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Metrics for National and Regional Assessment of Aquatic, Marine, and Terrestrial Final Ecosystem Goods and Services

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by

Paul Ringold, Colin Phifer, and Faye Andrews (editors)

Pacific Ecological Systems Division
Center for Public Health & Environmental Assessment

Paul Ringold, Project Officer

Pacific Ecological Systems Division
Center for Public Health & Environmental Assessment
Corvallis, Oregon 97333

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METRICS FOR NATIONAL AND REGIONAL ASSESSMENT OF AQUATIC, MARINE, AND TERRESTRIAL FINAL ECOSYSTEM GOODS AND SERVICES

Editors: Paul Ringold[1], Colin C. Phifer[2], Faye V. Andrews[3]

Contributors: Ted R. Angradi[4], Walter Berry[5], Timothy J. Canfield[6], Andrew Gray[7], Christina Horstmann[8], James S. Latimer[5], Amanda M. Nahlik[2], Dave Peck[2], Deborah Santavy[9,] Leah M. Sharpe[9], Kimberly M. Schuerger[10]

Contributors are listed in alphabetical order

1 U.S. Environmental Protection Agency (U.S. EPA), Pacific Ecological Systems Division, Center for Public Health and Environmental Assessment, Corvallis, OR 97333

2 U.S. EPA, Pacific Ecological Systems Division, Center for Public Health and Environmental Assessment, Corvallis, OR 97333 [Oak Ridge Institute for Science Education, Postdoctoral Fellow]

3 U.S. EPA, Pacific Ecological Systems Division, Center for Public Health and Environmental Assessment, Corvallis, OR 97333 [Oak Ridge Associated Universities, Student Services Contractor]

4 U.S. EPA, Great Lakes Toxicology and Ecology Division, Center for Computational Toxicology and Ecology, Duluth, MN 55804

5 U.S. EPA, Atlantic Coastal Environmental Sciences Division, Center for Environmental Measurement and Modeling, Narragansett, RI 02882

6 U.S. EPA, Groundwater Characterization and Remediation Division, Center for Environmental Solutions and Emergency Response, Ada, OK 74820

7 U.S. Department of Agriculture Forest Service, Resource Monitoring and Assessment Program, Pacific Northwest Research Station, Corvallis, OR 97333

8 U.S. EPA, Gulf Ecosystem Measurement and Modeling Division, Center for Environmental Measurement and Modeling, Gulf Breeze, FL 32561 [Oak Ridge Institute for Science Education Participant,]

9 U.S. EPA, Gulf Ecosystem Measurement and Modeling Division, Center for Environmental Measurement and Modeling, Gulf Breeze, FL 32561

10 U.S. EPA, Groundwater Characterization and Remediation Division, Center for Environmental Solutions and Emergency Response, Ada, OK 74820 [Oak Ridge Associated Universities, Student Services Contractor]

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TABLE OF CONTENTS

List of Tables

List of Figures

PREFACE

Ecologists and other biophysical scientists use a host of ecological metrics to observe, understand, assess, and predict ecosystem features. These metrics are defined by sets of principles well established by biophysical scientists; however, when biophysical scientists seek to provide information other scientists can use in their analyses, they need to identify and apply an added set of principles. The use of biophysical outcomes by social scientists, especially in the quantification of benefits, is one such clear and increasing need (U.S. EPA, 2009). The publication of "*What are ecosystem services? The need for standardized environmental accounting units*" by Boyd and Banzhaf (2007) offered the beginnings of a set of principles, well grounded in economic theory, that appeared to offer a way for biophysical scientists to identify the subset of ecological metrics that would meet the needs of benefits analysis. The purpose of this report is to describe how an interdisciplinary team translated the principles delineated by Boyd and Banzhaf into a set of practices and metrics applicable to a broad set of ecosystems and the ways in which people benefit from them.

This work focuses on metrics and principles for national and regional scales of analysis. As such, the metrics and the reports based on them are expected to be more useful for agents acting on behalf of collections of individuals as they interact with ecosystems, not necessarily individuals as they make decisions on a day-to-day basis. Having said this, the process and the results that our ecosystem experts went through, and the metrics identified, should be a useful starting point for those focusing on community scales of analysis.

This report is one part of a suite of three related tools developed by the U.S. Environmental Protection Agency (EPA) that use the same Framework:

1. **The National Ecosystem Services Classification System (NESCS Plus; Newcomer-Johnson et al., 2020)—**A classification system for ecosystem services that provides a consistent architecture and taxonomy, as well as the rationale for and a consistent delineation of the three dimensions of our shared Framework: beneficiaries, environmental classes, and attributes. It also contains tables of the relationships between dimensions.
2. **Metrics for National and Regional Assessment of Aquatic, Marine, and Terrestrial Final Ecosystem Goods and Services (FEGS Metrics; this report)—**The metrics and general process for metric selection, which are key elements of the related tools.
3. **FEGS Community Scoping Tool (Sharpe, Hernandez, & Jackson, 2020)—**Connects metrics and beneficiaries, specifically at community scales.

It is our hope that this set of three tools, as well as companion works, will improve the capacity of biophysical scientists to work with social scientists and therefore improve that nation's capacity to manage its ecosystems and to account for policy changes that affect them.

The conclusions of this report are only as good as the quality of the underlying data upon which it is based. These data, presented in this report, are based on published literature and EPA reports, websites, or other sources provided. Importantly, most of the data used in this report are used to illustrate concepts rather than to provide quantitative conclusions.

ACKNOWLEDGEMENTS

This report is the result of a team of social and natural scientists dedicated to finding the language and ideas that can serve to cross disciplinary boundaries and develop tools for better management and decision-making of the nation's natural resources. We thank the many scientists and partners who have been part of this effort and shared their knowledge and perspective on these topics, without which, we would not be able to complete this project. In particular, we thank the members of our Steering Committee (James Boyd, Resources for the Future; Rob Johnston, Clark University; Julie Hewitt, U.S. EPA Office of Water; Joel Corona, U.S. EPA Office of Water; Jeff Kline, USDA Forest Service; Charles Wahle, National Oceanic and Atmospheric Administration; and Tim Wade, U.S. EPA, Office of Research and Development) and the outside reviewers, including Drs. Brendan Fisher (University of Vermont), Kathleen Segerson (University of Connecticut), and V. Kerry Smith (Arizona State University), for their time and expertise in reviewing an earlier draft of this report. However, any errors, oversights or misunderstandings that may be embodied in this report are those of the authors rather than of these capable reviewers. We also thank RTI International under its contract with EPA (EP-W-15-005) for its help coordinating the Steering Committee and in the editorial and printing process of this report. We appreciate the scientific support staff that helped guide this report through the internal EPA review process and help ensure that it is broadly accessible.

The basis for many of the metrics selected for marine, aquatic and wetland ecosystems were based upon the National Aquatic Resource Surveys research; without the work of the many technicians and scientists who are a part of this team, we would lack this rich dataset from which we were able to draw so much from. We thank our federal partners at the U.S. Department of Agriculture's Forest Service for their expertise in forest ecology and helping identify metrics for this ecosystem. We thank the National Oceanic and Atmospheric Administration for loaning us one its chief scientists to serve on the Steering Committee.

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ACRONYMS AND ABBREVIATIONS

AIMS	Australian Institute of Marine Science
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FEGS	final ecosystem goods and services
FEMA	Federal Emergency Management Agency
FIA	Forest Inventory and Analysis
FWS	U.S. Fish and Wildlife Service
FWC	Fish and Wildlife Conservation GIS geographic information systems
NAPAP	National Acid Precipitation Assessment Program
NARS	National Aquatic Resource Surveys (U.S. EPA)
NESCS Plus	National Ecosystem Services Classification System (pronounced Nexus Plus)
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTU	nephelometric turbidity units
NWCA	National Wetland Condition Assessment
PCU	platinum cobalt units
RIDEM	Rhode Island Department of Environmental Management
StreamCat	Stream Catchment dataset
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

GLOSSARY

This glossary is adapted from a subset of the National Ecosystem Services Classification System (NESCS Plus) Glossary, December 2020 edition (the Glossary is updated periodically). The complete and most recent edition of the NESCS Plus glossary may be found at https://www.epa.gov/eco-research/national-ecosystem-services-classification-system-nescs-plus.

Beneficiary: The interests of individuals, groups of people, or organizations that drive their direct use or appreciation of an ecological end-product, resulting in an impact (positive or negative) on their welfare. *[Note the departure from common usage, in which a beneficiary is "a person who receives benefits," to focus instead on the person's awareness and interests, relative to final ecosystem goods and services, rather than to the persons themselves, because a single person with multiple interests can benefit from ecosystems in multiple and distinct ways.] Example:* A farmer relies on their land (space and soil) for producing crops and uses water from a nearby stream to irrigate in the summer.

Biophysical: Pertaining to the biological, chemical, and physical attributes of an ecosystem or environment.

Class: A main subdivision of a classification component, located within the top level of the component's hierarchical structure.

Classification system: 1. An organized (and often hierarchical) structure that, through well-defined categories, allows one to group similar elements together and to separate others. Pre-determined criteria define what should be considered similar or different, and these criteria are driven by the specific purpose for developing the classification system. 2. A method to group individual elements or features into collections similar in type, function, affiliation, behavior, response, or ontogeny. 3. An organized structure for identifying and organizing ecosystem services into a coherent scheme.

Demand: As an economic concept, the amount of an economic good or service that potential buyers would be willing and able to purchase at any given price. The level of demand for a good or service is also determined by many other factors, such as the availability and price of substitute and complementary goods and services and the income of the potential buyers. Demand is not the same as economic value, but it is a key determinant of the economic value of a good or service. Although most ecosystem services are not bought and sold in markets—so, there are no market prices—the economic demand for an ecosystem service can nonetheless be thought of as the amount that people would be willing and able to buy of the service if they could acquire it through a market transaction. *Context:* As an economic concept, demand can be influenced by, but is not the same thing as, a need, requirement, or desire. Like economic values, the demand for economic or ecosystem goods or services is a reflection of individuals' preferences for them.

Ecological production functions: Usable expressions (i.e., models) of the processes by which ecosystems produce ecological end-products, often including external influences on those processes. *Context:* The definition and specification of ecological production functions are used in modeling approaches to quantify how changes in one part of a natural system affect changes in another. *Example:* The relationship between a plant's uptake of soil nutrients (as an input) and its rate of biomass growth (as an output) can be represented by an ecological production function that can include one or more factors (e.g., soil nutrients, precipitation, altitude).

Economic production functions: A representation (often mathematical) of the input-output relationship involved in the production of an economic good or service by commercial/industrial establishments (i.e., firms) or non-commercial entities (e.g., households or individuals). Inputs typically include labor, physical capital (e.g., machinery), land, other natural resources (e.g., water) and raw materials, and other material supplies. Outputs are the goods or services produced by the process. The function also represents the technology, skill material supplies. Outputs are the goods or services produced by the process.

The function also represents the technology, skill level, and methods that are embedded within the production process.

Ecosystem attributes: A biological, physical, or chemical characteristic or feature inherent to an ecosystem/environment. *Context:* In economic valuation studies, ecosystem attributes refer to the set of ecological features that individually or as a group contribute to the enjoyment of a valued experience, such as a recreational or aesthetic experience (for example, a day of fishing). *Example:* Surface water clarity (e.g., as measured by Secchi disk depth) is an attribute of water in its natural environment, which can affect recreational users' enjoyment of the environment. In particular, it is an example of a water quality attribute.

Existence value: The enjoyment people may experience simply by knowing that a resource exists even if they never expect to use that resource directly themselves. *Context:* This is a component of "nonuse value" from early literature in environmental economics.

Final ecosystem good: Components of nature, directly enjoyed, consumed, or used to yield human well-being. The final ecosystem good (i.e., ecological end-product) is a biophysical quality or feature and needs minimal translation for relevance to human well-being. Furthermore, a final ecosystem good is the last step in an ecological production function before the user interacts with the ecosystem, either by enjoying, consuming, or using the good, or using it as an input in the human economy.

Final ecosystem service: The flows produced by final ecosystem goods and directly used appreciated or enjoyed by a human beneficiary. *Context:* Final ecosystem service flows occur at the "point of handoff" from natural systems to human systems. They are an essential concept for the economic valuation of ecosystem services because the value of a final ecosystem service embodies and includes the values of all intermediate ecosystem services that contribute to its existence. *Example:* The fauna present in forests, such as deer, are an example of an ecological end-product that provides final ecosystem service flows to commercial and recreational hunters who harvest them, as well as to recreational wildlife viewers who enjoy them in a non-consumptive way. The forest ecosystem's production of the forage that supports the deer populations is an example of an intermediate ecosystem service that contributes (as an input) to the final ecosystem service.

Flow: A variable measured over an interval of time. Flow measures are typically expressed as a rate per unit of time—e.g., annual income (dollars/year), daily nutrient load to surface water (pounds/day). *Context:* The distinction between "stocks" and "flows" is an essential concept for measuring natural capital (which is a stock concept) and the contributions of natural capital to human well-being (which is a flow concept).

Goods: Tangible items that are created through a production process and that may be acquired, used, or consumed by people for use as inputs in another production process or to satisfy other needs or wants. Goods can be represented and measured as "flows," such as the amount sold and transferred to new owners over the course of the year, or as "stocks," such as the amount stored in an inventory at the end of the year. *Context:* Two important features that distinguish goods from services are (1) their tangible nature and (2) their ability to be treated as stocks in certain contexts.

Human well-being: A multidimensional description of the state of people's lives, which encompasses personal relationships, strong and inclusive communities, meeting basic human needs, good health, financial and personal security, access to education, adequate free time, connectedness to the natural environment, rewarding employment, and the ability to achieve personal goals.

Indicator: 1. An interpretable value or category describing trends in some measurable aspect, often used singularly or in combination to generate an index. 2. A sign or signal that relays a complex message, potentially from numerous sources, in a simplified and useful manner. 3. An interpretable summary value that reflects the state of, or change in, a system or point of interest that is being evaluated. Indicators are derived from measures or metrics that correspond to components of well-being. Example indicators are perceived safety, lifestyle and behavior, and wealth. 4. A summary measure that provides information on the state of, or change in, the system that is being measured. Information based on measured data used to represent a particular attribute, characteristic, or property of a system.

Intermediate ecosystem service: Attributes of ecological structure or process that influence the quantity and/or quality of ecosystem services but do not themselves quantify as final ecosystem goods and services (because they are not directly enjoyed, consumed, or used). *Context:* A good or service can be an intermediate good or service in one situation and a final good or service in another situation. *Example:* Water in a river is an ecological end-product used in a final ecosystem service by a kayaker, but the same river water is an intermediate good or service to a hiker who appreciates a deer that drinks from that water.

Metrics and indicators: Direct or indirect measurements of an ecological end-product or attributes. If a metric can be consistently and reliably related to an end-product and a beneficiary, it can potentially serve as an indicator of final ecosystem goods or services.

Natural capital: An extension of the economic concept of physical capital—produced assets such as buildings, machinery, and equipment that are used in the production of economic goods and services—to ecosystem goods and services. Natural capital is the stock of natural ecosystems that yields a flow of valuable ecosystem goods or services into the future.

Non-use values: Human preferences for goods or services that are not associated with or derived from direct use or contact with them. For instance, individuals may care about or appreciate ecological end-products, even if they never directly use or see them – i.e., they may have non-use values for the existence of things like tropical forests or pristine lakes, even if they never visit them. Sometimes referred to as "passive use value," non-use values are theoretically distinct from "use values," although the boundary between use and non-use values is not always definitive. Different types of non-use value include existence value, option value, and bequest value. *Context:* The recognition that humans enjoy and benefit from ecosystems in ways that do not involve direct use is essential for developing a comprehensive accounting (e.g., economic valuation) of the total benefits provided by nature. *Example:* Individuals often value the assurance that threatened and endangered species are being protected, even if they will never see them in the wild, simply because they benefit from knowing that the species exist.

Services: Actions or processes performed by people or nature that benefit people. Services are typically intangible and non-storable and, in contrast to goods, which can be treated as "stocks" and measured at a specific point in time, services are "flows" from the service provider to the service consumer and are measured over a period of time (e.g., hourly access to and use of a gym facility). Unlike a good, which can exist (e.g., as part of an inventory) without being transferred to a consumer, the existence of a service requires that it be received by a human. The wants and needs of people are met through items (i.e., goods) and delivery of assistance (i.e., services). Economic, environmental, and social services reflect the three pillars of sustainability.

Stock: A quantity existing at a point in time, which may have accumulated or been produced in the past. Units of measurement are typically expressed in levels – e.g., wealth (dollars), physical assets (number of machines), and nutrient concentration (milligrams per liter)—that are present at a specific point in, or over a period of, time. Economic goods can be represented as a stock when they are accumulated, stored, or stockpiled—e.g., the stock of produce in a grocery store's inventory at the beginning of the year. Natural capital is also a stock concept, representing the level of wealth (productive natural capacity through ecosystem characteristics and processes, as well as the ecosystem goods) embodied within environments at a point in, or span of, time. *Context:* The distinction between "stocks" and "flows" is an essential concept for measuring natural capital (which is a stock concept) and the contributions of natural capital to human well-being (which is a flow concept).

EXECUTIVE SUMMARY

A central question for any policy analysis is, *What are the effects of this policy on human well-being?* For questions that involve ecosystem components, these analyses are aided by the availability of a set of models and metrics (or data) that link those models together. Often missing are “linking metrics” and, even more importantly, the specification of those linking metrics. Metrics of final ecosystem goods and services (FEGS) are important because they represent biophysical units linking ecological production to social production. They represent the subset of ecosystem quantities and qualities that are “handed off” from ecosystem scientists and models to social system scientists and models, as illustrated in **Figure ES**. Additionally, FEGS metrics are best expressed in units well understood by people representing a variety of fields and levels of expertise, so that theyare therefore useful in communicating ecosystem services or ecosystem status to those people. Overall, FEGS are those biophysical metrics that best facilitate social interpretation of ecological conditions that directly affect people’s welfare (Boyd et al., 2016).

In addition to FEGS, the linkage from ecological production to social production includes *intermediate* ecosystem goods and services (ecosystem processes and structures that contribute to the distribution and abundance of FEGS and are critical to understanding, assessing, predicting, providing early warnings, and ultimately to managing FEGS); and intermediate or final *economic* goods and services (e.g., crop harvests or retail food sales; these are metrics that depend on FEGS and are components of social systems).

This report specifies FEGS metrics for use in national and regional analysis of ecosystems and the human well-being arising from their use, appreciation, and enjoyment. National and regional analysis supports strategic purposes and provides context and a starting point for local analysis and decision making. *Strategic purposes* include allocating scarce management attention and making decisions about whether and how to allocate attention and effort to specific ecosystems, stressors, or places.

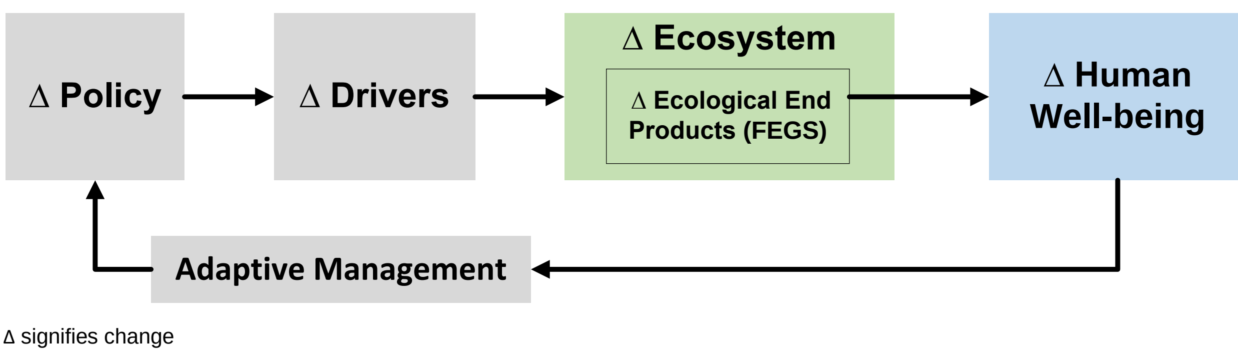


Figure ES. FEGS metrics are the subset of ecosystem features that best link to human well-being.

To identify reliable metrics, we developed a systematic, five-step process, guided by a Steering Committee of social scientists, and applied it to each of the ecosystems considered:

1. **Ecosystem Delineation:** explain how biophysical scientists bound ecosystems for practical purposes.
2. **Beneficiary Specification:** describe the beneficiaries to be considered for each ecosystem. These were adapted from a classification provided by the companion National Ecosystem Services Classification System—NESCS Plus (Newcomer-Johnson et al., 2020).

3. **Attribute Specification:** identify the biophysical components of nature (e.g., water, fauna) that link the ecosystem service and the beneficiary's interests. The attributes were drawn from a hierarchical list provided in NESCS Plus.
4. **Metric Specification:** describe the units of the attribute and specify ideal metrics for each FEGS.
5. **Data Availability:** consider the availability of appropriately scaled data for the ideal metric and propose alternative metrics when extensive, spatially explicit data are not available. These alternative metrics often represent surrogates or proxies for the ideal metric; it is important to note the limitations of surrogate data.

We identified 200 metrics for 45 beneficiaries across 7 ecosystems (coral reefs; estuaries; lakes; rivers and streams; wetlands; agricultural lands; forests). Virtually all types of beneficiaries directly experienced, or perceived, multiple FEGS metrics. This implies that any given benefits analysis may need to consider tracking multiple metrics. For most FEGS, data on the ideal FEGS metrics were not available and thus were often represented by other, often surrogate, metrics. Even for these "available" metrics, the spatially explicit extensive representations useful for assessment and social analysis are often not available. This poses a challenge for mapping FEGS, and for economic studies for which local abundance and scarcity is vital. Finally, there is a great diversity in the FEGS metrics identified and in their form.

This work should be interpreted and applied in the context of two companion efforts: NESCS Plus (Newcomer-Johnson et al., 2020) and the FEGS Community Scoping Tool (Sharpe et al., 2020) for communities to use in identifying those beneficiaries and metrics relevant to a given decision--making effort. These three efforts share a common language and single FEGS glossary. In addition, several other reports have been completed or are well underway to examine individual ecosystems, beneficiaries, and associated FEGS metrics. These include

- Work on lake water clarity (Angradi, Ringold, & Hall, 2018)
- A recreational fishery index (Hughes, Lomnicky, Peck, & Ringold, 2021)
- A review of the state of science of metrics for existence beneficiaries (Boyd, Johnston, & Ringold, In prep)
- A metric of wetland plants as used by native American peoples (Nahlik, Magee, & Blocksom, In prep).

The purpose of this collection of efforts is to improve the specification of critical linkages between ecosystems and human systems. By improving these linkages, decisions should more efficiently and reliably incorporate information about the benefits and costs of policy actions.

This work identified several important future research needs:

- More primary research on metrics to best link ecosystems to human well-being and also effectively communicate ecosystem status to beneficiaries. Much of the existing work-focuses on a generic, rather than a specific, beneficiary. This work suggests focusing on specific beneficiaries because they directly experience different attributes of the environment.
- A focus not only on the biophysical features that matter to people, but also on the temporal and spatial units of those features.
- More effort devoted to translating metrics of FEGS into terms clearly understandable to a variety of people.
- More efforts to include FEGS metrics in the design of modeling, monitoring, assessment, and reporting programs.

1. Introduction

For any policy analysis, a central question that decision-makers want answered is, *What are the effects of this policy on human well-being?* Addressing this question for policies that involve ecosystem components requires diverse scientists to quantitatively link their understanding of ecological and social systems. However, the "linking metrics" are often missing, particularly the specification of those linking metrics. The purpose of the research presented in this report is to improve this linkage between social and biophysical sciences and models by focusing on components of nature referred to as *final ecosystem goods and services* (FEGS). This report describes a framework for linking biophysical and social processes in decision-making and provides a method useful to identify FEGS for use in environmental assessment, monitoring, social analysis and planning.

Ecosystem services are ecosystem components and processes that contribute to human well-being (Millennium Ecosystem Assessment, 2005). The general conceptualization of ecosystem services was crystalized in 1997 as "the conditions and processes through which ecosystems and species that make them up sustain and fulfill human life" (Daily, 1997). This definition helped to recognize the overall connection between environmental qualities and quantities and human well-being and is useful for conveying the general importance of ecosystems to people. But this definition is too general to be useful in rigorous linked quantitative analysis appropriate for decision-making. Efforts to improve and standardize the definition and categorization of ecosystem services took a big step forward in 2001 when the United Nations' Environmental Program began a process to systematically organize and account for global ecosystem services (Costanza et al., 2017; Millennium Ecosystem Assessment, 2005). The result of this international effort was the 2005 Millennium Ecosystem Assessment proposing a framework classifying ecosystem services into four broad categories: provisioning (e.g., food), regulatory (e.g., water purification), cultural (e.g., recreation), and supporting services (e.g., soil) (Millennium Ecosystem Assessment, 2005).

The Millennium Ecosystem Assessment framework remains influential, but it has some drawbacks that make it difficult to develop metrics that represent the direct contribution of ecosystems to human well-being. Metric definition and data to quantify those metrics are a key part in any analysis process – what is measured and how? The lack of units suitable for ecosystem services in the context of economic analysis was underscored in theory by the U.S. Environmental Protection Agency's (EPA's) Science Advisory Board (U.S. EPA, 2009) and in practice by many analyses, including, for example, analyses of the benefits and costs of the U.S. acid rain program (Chestnut & Mills, 2005). That analysis found that despite the existence of a large ecological assessment program (NAPAP, 1992), benefit calculations were problematic due to a "lack of units of measure to gauge changes in the quality and quantity ecosystems services." This is perplexing, given the large ecological research and assessment programs dedicated to examining the effects of acid rain on ecosystems in the United States and the world (NAPAP, 1992, 2010).

The existing frameworks, definitions, and boundaries of ecosystem services were too ill-formed and inconsistent for integrated analysis (Nahlik, Kentula, Fennessy, & Landers, 2012). The lack of a causal relationship between changes in ecosystems and ecosystem services and human well-being make it difficult to conduct real-world environmental analysis (Boyd & Banzhaf, 2007). To address this shortcoming in metrics of analysis and to operationalize the ecosystem services concept, EPA's Sustainable and Healthy Communities research program is developing a set of tools to enable a wide range of users to utilize the FEGS Framework. Central to these efforts are the standardized metrics from the environment that biophysical scientists should seek to describe, understand, and predict, and that social scientists can use in benefits analysis. *FEGS are the biophysical metrics that best facilitate social interpretation of ecological conditions that directly affect people's welfare (Boyd et al., 2016).* These FEGS metrics are the currency of the FEGS Framework and serve as the units that should be used in interdisciplinary analysis of ecosystem services and in communicating the status and trends of ecosystems to people.

1.1 FEGS Framework

Photo: Recreational anglers directly interact with the environment in a myriad of ways. They directly enjoy the appeal of the site and the fish in the water. Measures of these ecosystem attributes comprise metrics of final ecosystem goods from these ecosystems for this beneficiary. Photo credit: EPA Flickr.

The FEGS definition we use expands upon on earlier work that described FEGS solely as the "biophysical components of nature that are directly enjoyed, consumed or used by people" (Boyd & Banzhaf, 2007). The broader definition reflects interdisciplinary interactions and analysis between economists and natural biophysical scientists. FEGS metrics are best understood as the linchpin in a series of linked production functions grounded in well-developed ecological production functions (Boyd & Krupnick, 2013).

Ecosystem Goods and Services Terminology

In the ecosystem services literature, natural scientists often use "ecosystem services" as a term encompassing both goods and services. Technically, final ecosystem *goods* are the tangible biophysical components of nature that are the direct source of final ecosystem *services*. Final ecosystem services are the flows produced by final ecosystem goods and directly used appreciated or enjoyed by a human beneficiary. For brevity, we use the term *final ecosystem goods and services* (FEGS) to encompass both concepts, although most of what we describe are goods rather than services. See the glossary for definitions of these and other terms.

Figure 1 illustrates the connection between the biophysical environment (on the left) and human communities and well-being (on the right). Biophysical functions generate ecological end products (final ecosystem goods) like wild fish in streams or fertile soil in fields, that people can use directly or appreciate in diverse ways. Some of these go through intermediaries before affecting human well-being: for example, tuna fish in the ocean (a final ecosystem good) are caught by commercial anglers (the beneficiary) and processed through an economic system (e.g., fish packing plants, truckers, and grocers, and then prepared for consumption in a house) before affecting human well-being. In contrast, an appealing view affects people directly. It is important to note that the mere fact that a biophysical quantity or quality is subject to regulation does notmake that quantity or quality a final ecosystem good or service. A final ecosystem good or service must be something that a beneficiary directly experiences or perceives, not simply something regulated or managed (e.g., dissolved oxygen or fish habitat) to manipulate the distribution or abundance of something else (e.g., fish).

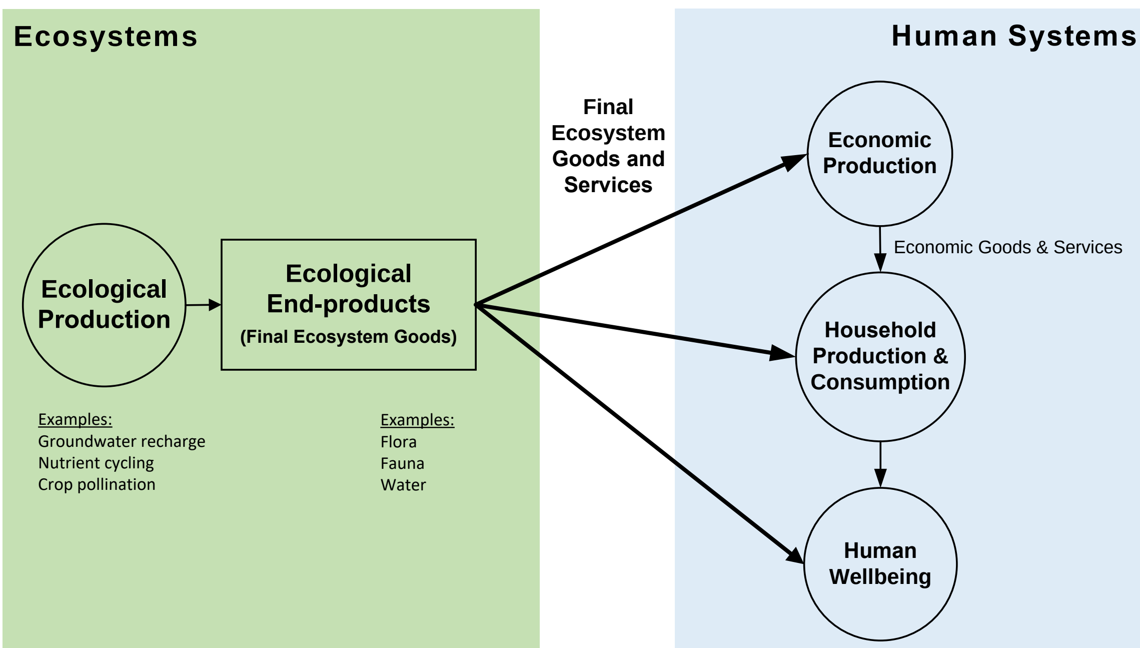


Figure 1. The FEGS Framework and taxonomy of linkages between the environment/ecosystems and human systems.
Source: NESCS Plus (Newcomer-Johnson et al., 2020)

As illustrated in Figure 1, ecological production provides final ecosystem goods. As these goods are used or enjoyed by people, they provide a service that enters into human systems of production. The specifics of this linkage depend on the beneficiary and the ecosystem. For example, for a recreational angler on a stream, watershed and stream processes control the distribution and abundance of fish in the water. The fish are a final ecosystem good; the angler's use or enjoyment of the fish is a final ecosystem service that enters into household production (center arrow between the boxes in Figure 1), which influences human well-being; in addition, the appeal of the site is also a final ecosystem service that directly affects human well-being (bottom arrow between boxes in Figure 1). A contrasting example is a city drinking water intake facility on a lake: complex watershed and lake processes influence the quantity and quality of the water available in the lake. Here, the water itself in the lake is a final ecosystem good. The municipal intake of water is the ecosystem service that enters into economic production (top arrow between the boxes in Figure 1) to produce an economic good, fresh water for use by people and industries. The treated water (the economic good) is sold to households and then enters into household production and influences human well-being.

1.2 Three Principles of the FEGS Framework

Three important principles of the FEGS Framework help to further distinguish it from other ecosystem service definitions and make ecosystem service analysis operational (Boyd & Krupnick, 2013):

1. It focuses on the direct **beneficiary** of the ecosystem service and the part of nature this beneficiary directly uses, appreciates or enjoys;
2. It focuses on **final ecosystem goods** that are clearly understood by beneficiaries and are directly enjoyed or used by people;
3. It delineates nature into discrete **ecosystems** with operational boundaries that can be linked to specific ecosystem services and beneficiaries.

These three principles make the FEGS Framework attractive to EPA's Sustainable and Healthy Communities program and other Federal, state and local environmental and natural resources agencies that are seeking ways to use ecosystem services in planning and decision-making (Olander et al., 2015; Posner, Getz, & Ricketts, 2016; The White House, 2014).

Beneficiaries. The first part of the FEGS Framework focuses on the users of nature or beneficiaries – a person, industry, or organization that directly uses or interacts with nature. *Beneficiaries are defined as the interests of individuals, groups of people, or organizations that use, appreciate or enjoy nature and an ecological end product.* In the examples earlier, the commercial anglersand the municipal drinking water facility are the beneficiaries. Understanding how beneficiaries directly interact with, use, and appreciate nature is key to the FEGS Framework. There is no single way in which people directly perceive or understand nature; rather people interact with and appreciate their environments in a variety of ways; seeing the environment from a beneficiary's perspective is critical for selecting meaningful metrics.

Final Ecosystem Goods. The second part of the FEGS Framework focuses on the components of nature recognizable and directly used appreciated or enjoyed, the final products of nature. This approach recognizes that the complex biotic and abiotic ecological interactions of nature have meaning to people especially as they influence the distribution, abundance, and quality of FEGS. These often invisible or less apparent cycles of nature are called intermediate ecosystem goods and services (Boyd et al., 2016; Lamothe & Sutherland, 2018) and are represented by the circle

"Ecological Production" in Figure 1. These critical processes and their relationships to FEGS are often only understood quantitatively by subject-area or technical experts, which makes it difficult for others to use or evaluate them consistently and meaningfully. The FEGS approach focuses on the biophysical goods that are directly experienced or perceived and distinguishes them from these essential intermediate processes. To be clear, intermediate ecosystem goods and services are enormously valuable and important to measure, monitor, and manage. For example, wetland denitrification (an intermediate ecosystem good) may minimize low estuarine oxygen levels (another intermediate ecosystem good) leading to more abundant fish for a subsistence angler (a final ecosystem good). In addition, when there are time lags between changes in intermediate and final ecosystem goods, the intermediate ecosystem goods may provide an early warning for changes in FEGS. What the FEGS concept does is to help provide an additional rationale, a social rationale, for an understanding of why these processes is important. We do not suggest that intermediate ecosystem goods and services have no economic value, rather their economic value is embedded in the value of the final ecosystem good and the service it provides. This is the same as in commercial markets where, for example, people make choices and place a value on different loaves of bread. The flour, yeast, sugar, and water in the bread and all of labor and systems to create the bread are part of the bread production system. Those components have value that is reflected in the retail price of the bread and are managed to yield the distribution, abundance, and quality of bread that people can purchase in the marketplace.

Ecosystems. The third part of the FEGS Framework is to organize and partition the natural world into distinct ecosystems. Defining and delineating these boundaries make accounting more tractable, complete, and consistent. Some ecological goods are composites of multiple ecosystems. For example, building on the recreational angler noted above, the appeal of a favorite fishing hole may depend on many ecosystems, including not only ocean, but also the adjacent riparian area and the forests, wetlands, urban areas, and agricultural systems in the viewshed (or really in the "sensory-shed", since sense of place includes the perception of all the body's senses). This last point of is an important part of the ecosystem specific delineation of the FEGS concept: *a FEGS is counted and quantified where it is enjoyed or used by the beneficiary*, not necessarily where it is produced or created. So for the recreational angler who catches salmon in a river, the ocean portion of the salmon's life is where intermediate production takes place that produces the angler's recreation where that recreation occurs.

The delineation of beneficiaries, ecosystems, and focusing on final ecological goods as the units of analysis helps to resolve the inconsistencies and double counting that may take place in other ecosystem service frameworks. The selection of the FEGS metric – the linchpin between biophysical and social scientists – is the key for successful integration between these different disciplines. Together, these three principles of the FEGS Framework can be used to improve analysis, decision-making, and communication when considering changes to policies that may affect the environment.

1.3 Using the FEGS Framework in Decision-making

EPA's Sustainable and Healthy Communities program is exploring the FEGS Framework as a means to more fully and consistently represent the environment and the values people place on it in decision-making. The general goal is to provide comprehensive information on all the ways in which ecosystems support people so that they can all be properly accounted for in decision-making. A well-chosen metric can improve the valuation studies economists often conduct or transfer from other studies when considering cost/benefits of policy changes. The FEGS Framework faciliates social analysis by economists and increases understanding by the public. This added clarity and translatability leads to better analysis, and communication (Boyd et al., 2016).

Figure 2 describes the general decision-making context in which policy analysts operate. Changes in policy impact a driver on the environment that can lead to changes in ecosystem patterns and processes. A subset of those changes are changes in FEGS, while many others are intermediate ecosystem goods or services. Those changes in FEGS impact human well-being. Finally, adaptive management allows for adjustments to policy changes if they do not have the desired or expected effect.

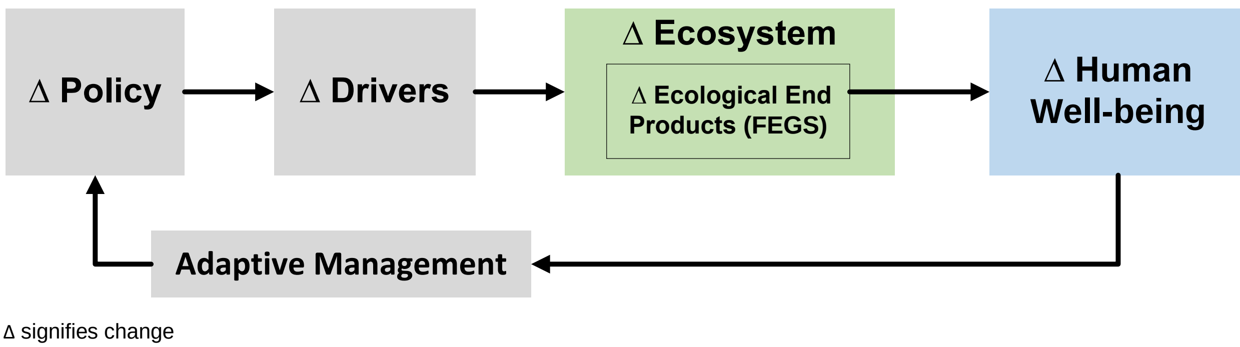


Figure 2. Conceptual model of the central role of FEGS in decision-making analysis by EPA's Sustainable and Healthy Communities program or other agencies.
In this model, a change in policy may impact a driver that effects the environment. FEGS capture the biophysical processes but can be described and communicated better, which makes them a better choice to include in social analysis. This figure is similar to Figure 1 in terms of the linkages between FEGS and human well-being but includes the policy impacts to drivers and the ecosystem.

Using the conceptual model shown in Figure 2, consider a change in acid rain policy. Changes in the Clean Air Act (policy change) resulted in changes in facility emissions (the driver) that—via intermediate processes in air, watershed, and aquatic ecosystems—yielded changes in biophysical outcomes, including chemical water concentrations and fish abundance (ecosystem changes). Some of these outcomes will be better at facilitating accurate and meaningful social well-being analysis than others (Boyd et al., 2016). The ones that beneficiaries experience, perceive, and understand directly are what will be useful FEGS metrics. Changes in these FEGS lead to changes in human well-being. The absence of models predicting FEGS and information on FEGS has been a primary obstacle to estimating the ecological benefits of acid rain policy (Chestnut, Mills, & Cohan, 2006).

The challenge for a national agency like the EPA is how to systematically and consistently consider the full range of benefits at national and regional scales. Our national and regional scale charge has two corollaries that relate to the spatial scale or specificity of the suggested metric:

- We seek to be generally correct and consistent; this is in contrast to a local reporting requirement in which one must be specifically correct but consistency is of little matter. For example, at the national or regional scale, it might be sufficient to know that some percentage of forests are deciduous. At the local level one might want to know if a specific forest contains *Quercus buckleyi* Nixon & Dorr, live oak.

- National and regional data require time to assemble and are usually published several years after the period of time they cover; for example, the U.S. Geological Survey (USGS) *Estimated Use of Water in the United States in 2005* was published in 2009 (Kenny et al., 2009); the EPA *National Lakes Assessment 2012* was published in 2016 (U.S. EPA, 2016a); and the National Oceanic and Atmospheric Administration (NOAA) *Fisheries of the United States, 2018* was published in 2020 (NOAA, 2020b), Therefore, such national or regional data and the reports based on them are not useful for immediate decisions, such as deciding where to go fishing this weekend, but rather for longer range or strategic purposes, such as providing insights as to whether the nation should allocate resources to one problem, issue, or place rather than another. This is consistent with our purpose: to develop metrics that represent how human well-being and communities connect with and interact with nature.

As such, our metrics and methods, and the reports based on them, are expected to be more useful for agents acting on behalf of the beneficiaries than for the beneficiaries directly as they make decisions on a day-to-day basis. Having said this, the process and the results that our ecosystem experts went through to define beneficiaries and the metrics that matter to them should be a useful starting point for those focusing on community scale actions.

This report is one part of a suite of three FEGS-related tools developed by EPA that use the FEGS Framework at both national and community scales (see **Figure 3**):

1. **The National Ecosystem Services Classification System (NESCS Plus; Newcomer-Johnson et al., 2020)—**A classification system for ecosystem services that provides a consistent architecture and taxonomy, as well as the rationale for and a consistent delineation of the three dimensions of our shared Framework: beneficiaries, environmental classes, and attributes. It also contains tables of the relationships between dimensions.
2. **Metrics for National and Regional Assessment of Aquatic, Marine, and Terrestrial Final Ecosystem Goods and Services (FEGS Metrics; this report)—**The metrics and general process for metric selection, which are key elements of the related tools. Information and methods in this report also provide a starting point for community decisions on which metrics to use in considering their decision.
3. **FEGS Community Scoping Tool (Sharpe et al., 2020)—**Connects beneficiaries and metrics, specifically at community scales. This allows community-level decision-makers to identify the set of prioritized FEGS specific to a community.

Together, these three pieces provide a comprehensive approach to using the FEGS Framework at national and community scales.

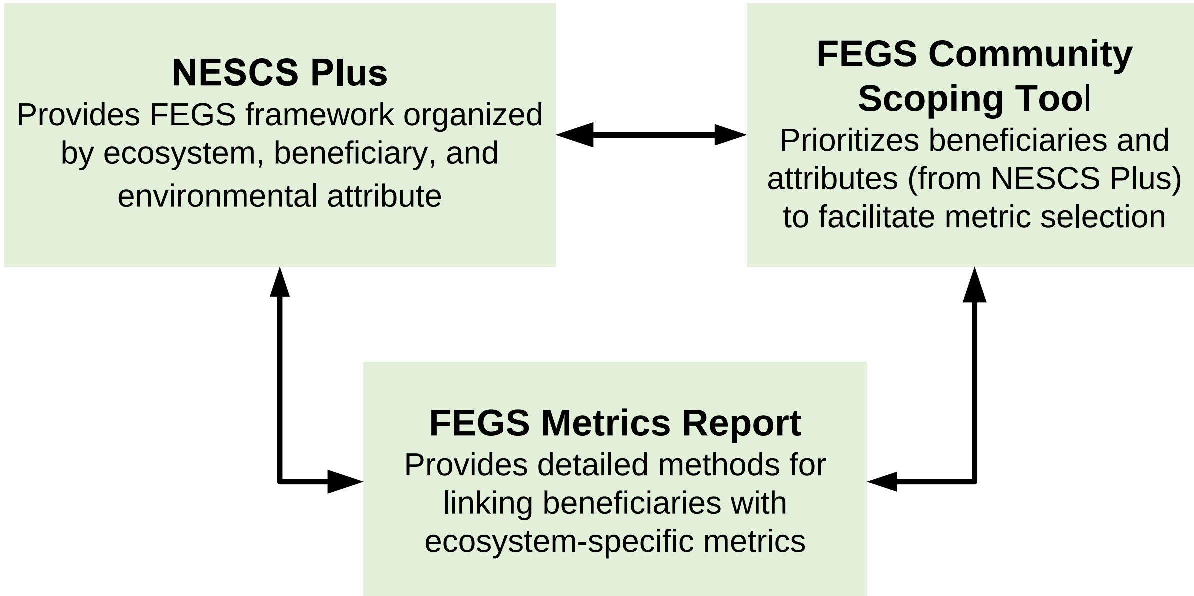


Figure 3. Relationship between NESCS Plus, FEGS Community Scoping Tool, and FEGS Metrics (this report).
Together these tools allow one to identify ecosystem service beneficiaries, prioritize community values, and select appropriate metrics for evaluation that reflect community interests.

1.4 FEGS Metric Selection Process

Specification of FEGS metrics is important because these are the specific tangible biophysical features or qualities that are the objects of management, communication, and social analysis. Biophysical scientists use an enormous number of metrics to describe, understand, predict, and assess ecosystems. Many of these metrics, however, may not be directly meaningful to people absent significant technical translation. FEGS metrics, in contrast, represent ecosystems in units that people, including policy makers and agencies that represent beneficiaries' interests, can readily understand. These FEGS metrics can be useful in decision-making and they should be considered in social analyses, including cost-benefit and trade-off analysis. The result of the inclusion of FEGS metrics in analysis will be improvements in the connection between biophysical and social processes, which will in turn provide a more complete and accurate assessment of policy changes.

We are not the first to address this issue; in fact, social scientists have a well-developed set of qualitative methods to address such issues (e.g., Champ, 2017; Desvousges & Smith, 1988; Morgan & Krueger, 1997; Weber & Ringold, 2012), and those methods have been applied for this purpose (e.g., Avolio et al., 2015; Daniel, 2001; Morton, Adamowicz, Boxall, Phillips, & White, 1993; Ribe, 1989; Schiller et al., 2001; Weber & Ringold, 2015, 2019). Efforts such as these are important for linked analyses and for our work. They inform our starting points and can be used to evaluate our metrics. We hope to stimulate more of this intensive work as a result of our efforts. However, in some instances, these applications have focused on the general ways in which people benefit from ecosystems without partitioning by specific beneficiaries that use and interact with nature in different ways. If beneficiaries differ in what they directly perceive in ecosystems then this practice would lead to misspecification of FEGs metrics. Because there is heterogeneity in beneficiary preferences, we believe that tracking preferences by beneficiary is important (Ringold, Boyd, Landers, & Weber, 2009; Ringold, Nahlik, Boyd, & Bernard, 2011).

In some cases, the needs of the beneficiary are well known; For example, it is well documented that salt reduces the value of irrigation water (Shannon & Grieve, 1998) or that the presence of alien mollusks can degrade water intake systems for domestic purposes or for thermoelectric cooling along a river or lake (Isom, Bowman, Johnson, & Rodgers, 1986; Nakano & Strayer, 2014). However, even in these cases, where the needs of the beneficiaries are well known, the full set of metrics is less clear: do pathogens matter for irrigators of crops not directly consumed? How does the potential for scaling and corrosion from source water affect thermoelectric cooling? For other beneficiaries, needs may be less well known, or may differ considerably depending on what different beneficiaries directly perceive in ecosystems. In those cases, there are not consistent methods to propose or select FEGS metrics on a comprehensive basis. Thus, at the outset of our work, there was no single existing method to identify the set of metrics for a wide variety of diverse beneficiaries as they interact directly with ecosystems.

For use as FEGS, biophysical metrics must not only meet the needs and requirements of ecosystem analysis, but also the needs of social scientists. In this vein, Schultz and his colleagues (Schultz, Johnston, Segerson, & Besedin, 2012) note that biophysical metrics must meet four criteria: measurability, interpretability, applicability, and comprehensiveness. EPA, elaborating especially on the biophysical requirements in more detail developed a list of 15 guidelines to evaluate the suitability of biophysical metrics in a consistent manner for ecological sampling and assessment (Jackson, Kurtz, & Fisher, 2000). One of the 15 guidelines includes consideration of linking the metric to management action. In contrast to very specific detail provided on how to think about the other guidelines, the guidance provided for relevance to management action is vague. Further, since management action often appropriately focuses on intermediate goods and services as a means to manage FEGS (e.g., Water Quality Standards; U.S. EPA, 2003b), guidance to focus on management actions is vital, but not sufficient to support linked analyses or even to communicate effectively with beneficiaries. Since FEGS serve as the interface between biophysical and social systems, they represent a way to provide support for these guidelines and even to extend them.

Consistent with this requirement for joint validity, we designed a process in which biophysical scientists and social scientists could collaborate and develop a set of linking metrics. Our process grew out of a series of interactive workshops with the goal of identifying a shared conceptual foundation to uniformly and consistently define metrics of FEGS. Beginning in 2008, the EPA FEGS working group organized interdisciplinary workshops with social and natural scientists and other experts to discuss ecosystems of estuaries, streams and rivers, and wetlands (Ringold et al., 2009; Ringold, Nahlik, Boyd, & Bernard, 2008). These workshops led to the development of the boundaries, organizing concepts, and principles of the FEGS concept and its potential relevance to the EPA in its regulatory and scientific function. Building on the discussion and success of these initial workshops, principles were refined (Landers & Nahlik, 2013; Ringold et al., 2009), additional workshops were organized, and additional experts were invited to participate in the process. This process for consistent metric selection for ecosystem-specific beneficiaries is described in detail in the Methods section.

1.5 Report Objectives

The objective of this report is to describe not only FEGS metrics generated for a diverse group of beneficiaries interacting with nature in seven ecosystems across the country, but also the key steps of the dialog and process of metric generation that structured our process. This report can be used by other environmental professionals seeking metrics for ecosystem service analysis. The results of this work are intended to support national and regional decision-makers who operate on behalf of the beneficiaries' interests. The methods and narrative laid out in this report provide the rationale and means to select meaningful metrics that can represent nature's contributions to human well-being.

2. Methods

We designed an approach to use expert knowledge and a structured process to identify metrics of FEGS for selected ecosystems. We utilized expert knowledge by assembling a team with two major sets of expertise: (1) biophysical scientists familiar with the principles of metric specification (Dale & Beyeler, 2001; Jackson et al., 2000; McKenzie, Hyatt, & McDonald, 1992) and with specific ecosystems; and (2) social scientists familiar with methods of valuation of both use and non-use existence values. The combined team met three times for workshops in 2016, 2017, and 2018 (Hall, 2017, 2018; Phifer, 2019) to refine their understanding of FEGS, develop a structured process, and propose a set of metrics as an illustration of the methods. An important part of the design of our work is to set the expectation that the ecosystem experts would serve as "champions" for FEGS perspectives in their future work.

Because so much of this work is very ecosystem-specific, we began with the classification of ecosystems from NESCS Plus (or, in the terminology of that system, "Environment Classes"), as shown in **Table 1**. At the highest level, ecosystems are categorized as aquatic or terrestrial. Conceptually, this delineation is consistent with how state and Federal agencies that interact with the environment are organized and how these agencies design monitoring programs. Thus, that dichotomy aligns with environmental sampling programs that already exist: the U.S. Forest Service has an extensive sampling program for forest resources, NOAA tracks coral reef resilience and the EPA and USGS track aquatic ecosystems. The ecosystem-based delineation also corresponds to satellite-based ecosystem classification systems that form the basis of environmental or natural resources spatial analysis, including the USGS National Land Cover Database. These classes are then further subdivided into subclasses and still more detailed subclasses.

We assembled seven ecosystem teams from the full set of ecosystems (or environment classes) listed in NESCS Plus. These are denoted by an asterisk in Table 1. Three are from the Subclass 1 category: forests, wetlands, and agroecosystems; three more are from the Subclass 2 category: rivers and streams, lakes, and estuaries; and one, coral reefs, is a subset of the Subclass 2 category near coastal marine. Agroecosystem analysis also added subdivisions to the listed environmental classes in some of their analyses. These specifications are provided in the extensive tables in the Appendix under the headings Environmental Class, Environmental Sub-Class, and Ecosystem.

Table 1. Ecosystem Classification Used by NESCS Plus

Environment Class	Environment Subclass I	Environment Subclass II
Aquatic	Open Water	Rivers and Streams*
		Lakes and Ponds*
		Near Coastal Marine*/Estuarine*
		Open Oceans and Seas
	Wetlands*	Woody Wetlands
		Emergent Herbaceous Wetlands
Terrestrial	Forests*	Deciduous Forest
		Evergreen Forest
		Mixed Forest
	Agroecosystems*	Pasture/Hay
		Cultivated Crops
	Grasslands	Grassland/Herbaceous
	Scrubland/Shrubland	Shrub/Scrub
	Tundra	Lichens
		Moss
		Dwarf Scrub
		Sedge/Herbaceous
	Ice and snow	Perennial Ice/Snow
	Urban/suburban	Developed Open Space
		Developed Low Intensity
		Developed Medium Intensity
		Developed High Intensity
	Barren/rock and sand	Barren Land (Rock/Sand/Clay)

* Denotes the seven ecosystems (referred to as environment classes in the NESCS Plus system) for which metrics were developed in this report. Note that coral reefs are not explicitly listed, but are a subset of the Near Coastal Marine subclass II.

The structured process for proposing metrics asked each ecosystem team to work through the following five steps:

Step 1. **Ecosystem Delineation:** explain how biophysical scientists bound ecosystems for practical purposes.

Step 2. **Beneficiary Specification:** describe the beneficiaries to be considered for each ecosystem.

Step 3. **Attribute Specification:** identify the biophysical components of nature that links with the ecosystem service and beneficiary's interests.

Step 4. **Metric Specification:** describer the units of the attribute and discuss the difference between ideal and available metrics.

Step 5. **Data Availability:** consider the availability of appropriately scaled data for the proposed metric.

In addition to these steps, the teams also presented visualizations of the candidate metrics and made some preliminary steps to evaluate their candidate metrics. The steps are described in more detail in the remainder of this section. **Section 3, Results,** is organized by ecosystem and includes the names of the team members, the ecosystem delineation, the beneficiaries, and the FEGS metrics for each ecosystem-specific beneficiary organized in comprehensive tables. These beneficiary-specific tables report the metrics for the ecosystem services provided by each ecosystem considered. These tables are a subset of the columns in the more detailed tables provided in the Appendix (which is also provided as a sortable and filterable Excel file). The Appendix tables include a row with the corresponding column designation in the tables provided in **Section 3** or the comment "not shown".

Because of the ecosystem delineation and the (general) reliance on ecological and environmental sampling programs for metrics, different teams of ecologists and other biophysical experts with knowledge of each system selected the metrics and beneficiaries for each ecosystem. As a consequence, there are differences in the metrics selected or in the specific units, reflecting the different availability of datasets.

2.1 Step 1: Ecosystem Delineation

For each ecosystem considered, the boundaries and scope must be clearly defined and delineated so that analysts know what features to include or exclude and so that these boundary decisions are clear for users of the results. In this step, the teams defined issues such as the landward boundary of streams and lakes, the upstream boundary of estuaries, and the definition of forest land. Ecosystem teams typically chose boundaries used by ecological sampling programs for regional or national scales (e.g., the U.S. Department of Agriculture [USDA] Forest Service Forest Inventory and Analysis [FIA] program; EPA's National Aquatic Resources Surveys [NARS]). The clear boundaries of the FEGS Framework implementation help to make it operational and useful for complete ecosystem accounting. At the same time, it is important to recognize that some beneficiaries may not recognize these ecological boundaries. This is particularly the case when site appeal is involved. Here, beneficiaries integrate their experience across all evident ecosystems in making judgments on site appeal, and practical, beneficiary-centered operational judgements must sometimes be made that may breach the otherwise useful boundary definitions.

2.2 Step 2: Beneficiary Specification

Here, our teams began with the classification of beneficiaries from NESCS Plus (Newcomer-Johnson et al., 2020), shown in **Table 2**. This beneficiary-first approach allows ecosystem service researchers to first identify what is important and appreciated at a human scale and then develop appropriate biophysical metrics.

Table 2. Beneficiary Classifications from NESCS Plus

These are used to systematically identify beneficiaries who directly use, interact with, or directly perceive nature. Ecosystem teams used this classification to identify ecosystem-specific beneficiaries.

Beneficiary Class and Description	Beneficiary Subclasses
Agricultural *Beneficiaries who use the environment for agricultural or forest production activities*	Livestock Grazers; Agricultural Processors; Aquaculturists; Farmers; Foresters; Other Agricultural Beneficiaries
Commercial/Industrial *Beneficiaries who directly use the environment for industrial or commercial production activities not included in the other categories*	Food Extractors; Timber, Fiber, and Ornamental Extractors; Industrial Processors; Private Energy Generators; Pharmaceutical and Food Supplement Suppliers; Fur/Hide Trappers and Hunters; Private Drinking Water Plant Operators; Commercial/Industrial Property Owners
Government, Municipal, Residential *Governmental, military, and residential beneficiaries who make direct use of the environment in ways not included in the other categories*	Municipal Drinking Water Plant Operators; Residential Property Owners; Public Sector Property Owners; Military/Coast Guard; Public Energy Generators
Transportation *Military and commercial beneficiaries who use the environment as a medium to transport goods or people*	Transporters of Goods; Transporters of People
Subsistence *Beneficiaries who use the environment to support subsistence activities*	Water Subsisters; Food and Medical Subsisters; Timber, Fiber, and Fur/Hide Subsisters; Building Material Subsisters; Other Subsisters
Recreational *Beneficiaries who use the environment to support recreational activities*	Experiencers and Viewers; Food Pickers and Gatherers; Hunters; Anglers; Waders, Swimmers, and Divers; Boaters; Other Recreational
Inspirational *Beneficiaries who use or appreciate the environment as a source of inspiration*	Spiritual and Ceremonial Participants and Participants of Celebration; Artists; Other Inspirational
Learning *Beneficiaries who directly rely on the environment for educational or scientific research activities*	Educators and Students; Researchers
Non-Use *Individuals who benefit from the environment in ways that do not require or are not associated with direct use of or contact with a final ecosystem good*	People Who Care (Existence); People Who Care (Option /Bequest)
Humanity *Everyone, regardless of whether they actively recognize or appreciate the final ecosystem good, because they are available to everyone and used by everyone to live (e.g., air for breathing)*	All Humans

The teams then chose specific beneficiaries from within the NESCS Plus subclasses; these are frequently more specific than the lists of beneficiaries available elsewhere (Landers & Nahlik, 2013; Newcomer-Johnson et al., 2020; Ringold et al., 2009; Ringold, Boyd, Landers, & Weber, 2013; Ringold et al., 2011). This additional level of specificity was required by ecosystem teams to specify attributes and metrics of direct relevance. For example, the NESCS Plus identifies anglers as a subclass of recreational beneficiaries. Within this subclass, the ecosystem teams for this effort identified catch-and-eat anglers and catch-and-release anglers. The distinction between anglers who consume their catch and those who release their catch affects the FEGS metrics that might be included: the presence of contaminants in the fish flesh in concentrations relevant to human health (e.g., mercury concentration) are highly relevant to a catch-and-eat angler, but not to a catch-and-release angler.

The ecosystem teams purposefully selected a set of wide variety of beneficiaries. The goal was to select a diverse set of beneficiaries to evaluate the utility of this approach across a broad spectrum. The beneficiaries include both direct consumptive users (e.g., waterfowl hunter), non-consumptive users (e.g., lake-front homeowners who enjoy the view), and non-use beneficiaries (e.g., those holding existence values) to include all types of beneficiaries necessary for a total economic benefits analysis. The beneficiaries selected were not assumed to be the most important—we have no way of establishing that, especially in the absence of a policy context—rather, beneficiaries were selected to demonstrate the potential of the FEGS Framework for EPA's Sustainable and Healthy Communities program and other organizations.

A difficult, but critically important, beneficiary subclass is the existence beneficiary, who appreciates the existence of a system with the expectation that they will never directly use or experience the system. In some circumstances, the benefits of ecosystem change attributable to this beneficiary can be quite large (Johnston, 2018). In addition, specification of biophysical units for this beneficiary are among the most difficult to define (Turner, Georgiou, & Fisher, 2008). Therefore, all ecosystem teams (except for the agricultural systems team) were asked to propose biophysical metrics for this beneficiary that represented a measure of the ecosystem's overall health or integrity. Their choices here were a subject of much discussion between the ecosystem experts and the Steering Committee. Those discussions have prompted further analysis, including a thorough state-of-the-science review (Boyd et al., In prep)

The beneficiaries selected for each ecosystem are shown in **Table 3**.

2.3 Step 3: Attribute Specification

Having specified an ecosystem and a beneficiary, the next step to metric identification was to ask as a heuristic question, *what matters to this beneficiary?* The answers led ecosystem experts to specify the general features of the environment that matter directly to each beneficiary. We termed these general features "attributes" of nature. This general specification then allowed the ecosystem teams to think more specifically about an appropriate metric. For example, swimmers in a lake care about water conditions—Is it safe to swim in? Is it clear or murky? What is the temperature in summer? These general attributes of the lake water (safety, clarity, temperature) matter to the specific beneficiary (swimmers) and so are important to measure and describe.

To simplify this step and make consistent attribute selections, we developed what eventually became a standardized, hierarchical set of attribute terms, shown in **Table 4**. Attribute categories are structural elements of NESCS Plus (2020) and are described in more detail there and in our shared glossary. These categories cover the basic components of all ecosystem (e.g., water, flora, fauna). The attribute subcategories further subdivide the attribute categories. When identifying metrics for their beneficiaries, ecosystem teams first identified the relevant attribute categories and subcategories. Within these prescribed categories and subcategories, ecosystem teams selected a more specific attribute; these were not prescribed and reflected the particulars of the specific beneficiary.

Table 3. Ecosystem-specific Beneficiaries Considered for this Report by NESCS Plus Beneficiary Class and Subclass

Key: — no specific beneficiary chosen. SUPs = stand-up paddle boarders.

Beneficiary Class	Beneficiary Subclass	Coral Reefs	Estuaries	Lakes	Rivers	Wetlands	Agriculture	Forests
Agricultural	Aquaculturists	Coral nurseries	Shellfish growers	—	—	—	—	—
	Farmers	—	—	—	—	Cranberry farmers	Crop farmers	—
	Foresters	—	—	—	—	—	—	Timberland owners/ timber growers
Commercial/ Industrial	Commercial Anglers	—	Commercial anglers	—	—	—	—	—
	Pharmaceutical and Food Supplement Suppliers	Extractors / bio-prospectors	Extractors / bio-prospectors	—	—	—	—	—
	Private Energy Generators	—	—	—	Thermoelectric cooling	—	—	—
	Timber, Fiber, and Ornamental Extractors	Reef ornamental extractors	—	—	—	—	—	Timber extractors
Government, Municipal, Residential	Residential Property Owners	Coastal property owners	Coastal property owners	Lakeshore property owners	River front property owner	—	Farmland property owners	Homeowner with some trees living next to forested area
	Transporters	—	Barge or ferry	—	—	—	—	—
Learning	Agricultural Landscape	—	—	—	—	—	Educators/ researchers	—
Non-use	People Who Care	Existence values	Existence values	Existence values	Existence values	Existence values	—	Existence values
Recreational	Anglers (recreational)	Catch & release, catch & eat	Catch & release, catch & eat	Catch & release, catch & eat	Catch & release, catch & eat	—	—	—
	Boaters	Kayakers, SUPs, & boaters	Kayakers, SUPs, and boaters	Power boaters	—	Kayakers, SUPs, and boaters	—	—
	Food Pickers & Gatherers	—	—	—	—	—	—	Recreational huckleberry pickers
	Hunters	—	—	—	—	Waterfowl hunters	Deer, waterfowl, & small game hunters	—
	Swimmers, Waders, Divers	Scuba divers and snorkelers	—	Swimmers	Swimmers	—	—	—
Subsistence	Food and Medicinal Subsisters	Anglers (subsistence)	Anglers (subsistence)	Wild rice harvesters Anglers (subsistence)	Anglers (subsistence)	Native American medicine subsisters	—	Elk hunters

Table 4. Prescribed Attribute Categorization Used to Describe the Physical Components of the FEGS Metric

Attribute Category	Attribute Subcategory
Atmosphere	Air quality Wind strength/speed Precipitation Sunlight Temperature
Soil/Substrate	Soil quantity Soil quality Substrate quality Substrate quantity
Water	Water quality Water quantity Water movement
Fauna	Fauna community Edible fauna Medicinal fauna Keystone fauna Charismatic fauna Rare fauna Pollinating fauna Pest predator/depredator fauna Commercially important fauna Spiritually/culturally important fauna
Flora	Flora community Edible flora Medicinal flora Keystone flora Charismatic flora Rare flora Commercially important flora Spiritually/culturally important flora
Fungi	Fungal community Edible fungi Medicinal fungi Rare fungi Commercially important fungi Spiritually/culturally important fungi
Other Natural Components	Fuel quality/quantity Fiber material quantity/quality Mineral/chemical quantity/quality Presence of other natural materials for artistic use or consumption (e.g., shells, acorns, honey)
Composite (and Extreme Events)	Site Appeal Ecological condition Open Space Extreme Events

Attribute categories, as structural elements of the classification system, are mutually exclusive. For example, either something is fauna or it is not—it cannot be both fauna and water. There were two exceptions to this, the Extreme Events category and the Composite category. Extreme Event attributes encompass such aspects of the environment that serve to increase or decrease the likelihood that beneficiaries will experience extreme events such as fire and flooding. Composite attributes encompass aspects of the environment that are the result of multiple individual attributes working together, such as the aesthetics of a landscape. Both of these categories are the result of multiple attributes working together across those mutually exclusive categories. A beneficiary, however, experiences them in their totality, which is why they are included as such in the attribute categorization.

Attribute subcategories reflect how a beneficiary interacts with the attribute category (related to the use itself). These are typically not mutually exclusive. For example, Pacific salmon are edible, commercially important, and spiritually important to Northwest tribes, and thus could be included in three subcategories of fauna: edible fauna, commercially important fauna, and spiritually/culturally important fauna. Different beneficiaries will be concerned with one aspect over another.

In addition to providing consistency across the ecosystem teams' processes and metric tables, the attributes also provide a connection point across FEGS tools. The attribute categories are used in NESCS Plus and both the categories and subcategories are used in the FEGS Community Scoping Tool.

The attributes selected for each beneficiary are identified for each ecosystem and are listed as in the tables in **Section 3, Results**, and the Appendix.

2.4 Step 4: Metric Specification

After identifying the general biophysical attributes that matter to each beneficiary, ecosystem experts then focused on identifying metrics that would be of direct relevance to a beneficiary. Metrics are more specific than general attributes; they are the biophysical parts of nature that natural scientists model, measure, and monitor directly, often as part of environmental quality programs. In contrast to the previous steps, where ecosystem specialists had a defined list of beneficiaries and attributes, there is no comparable compact list of metrics to choose from. Rather, ecosystem specialists often have a long list of potential metrics. For example, consider a purely ecological metric: in the process of developing a multimetric index of biotic integrity for macroinvertebrates, ecologists start with hundreds of candidate metrics just for one biotic assemblage (Stoddard et al., 2008). In aquatic ecosystems, this list of hundreds of metrics is complemented by lists that are equally long for landscape metrics, riparian structure, physical habitat, chemistry, and other assemblages. The challenge for ecosystem specialists is then to select the subset of metrics that are directly meaningful to beneficiaries.

For a few beneficiaries, ecosystem specialists identified a single metric that matters; for most beneficiaries, several metrics were suggested. We left the decision about the number of metrics to use for each beneficiary up to the best professional judgement of each ecosystem expert, though their selection was subject to feedback from their peers and oversight from the Steering Committee. The notion that people might directly experience or perceive multiple metrics of an ecosystem is consistent with market consumer decisions. From the simplest purchase (e.g., socks or bandanas) to the most complex (a house or a car), consumers make decisions on the basis of multiple attributes of the good or service that directly matter to them. Most purchases involve weighing multiple metrics and selecting one consumer item that matches the consumer interests; similarly, many ecosystem services are best represented by multiple metrics.

When selecting metrics, we made a distinction between ideal metrics and currently available metrics. Ideal metrics are ones most consistent with FEGS concepts. They reside in the right location in the set of linked production functions for the relevant beneficiary; they can be measured in continuous form; and in concept, they meet the other requirement for metrics (e.g., Jackson et al., 2000). We found that data on the ideal metrics were often not available. To provide guidance to users, ecosystem specialists also identified available metrics—metrics related to the ideal metric but for which data were available, especially at national and regional scales. These available metrics are shown in the Results section of this report. We also list the ideal metrics in the Appendix.

Available data are often surrogates for the ideal metrics. An extensive literature summarizes issues with the use of surrogacy (e.g., Hunter et al., 2016). In our Framework, surrogates are often either intermediate ecosystem goods (i.e., to the left of final ecosystem goods in the lefthand box in Figure 1) or economic goods or other social measures (i.e., the righthand box in Figure 1). Two examples illustrate the limitations, and therefore our reservations, regarding the use of surrogates for FEGs:

- Allison, Lubchenco, & Carr (1998) showed that habitat, in the form of marine reserves, is necessary but insufficient as a tool to manage valued ecosystem components, such as some commercial fish populations. Similarly, Lindenmayer and Likens (2011) suggest that management of indicators or flagship species may be necessary but are insufficient to maintain biodiversity and that "in some circumstances, the alternative of direct measurement of particular entities of environmental or conservation interest will be the best option".
- Maunder et al. (2006) point out the limitations of socio-economic measures, such as fish landings, or catch per unit effort as a surrogate for fish abundance. They note that catch as a function of a "unit of effort" varies over time and space, as well as with technology and skill, environmental factors, target organism size and taxon, and management practices, and therefore, the direct use of catch per unit effort estimates of fish abundance may lead to erroneous management decisions.

While such surrogate measures may be the best available data set, they must be used with recognition that the management goal is not the surrogate, but something else. It should also prompt the collection of data that are a more reliable representation of the FEGS.

Another issue ecosystem teams had to address is how much biophysical or social translation should be embedded in metrics. A metric with more translation may be more meaningful but may raise other issues. For example, water clarity is one factor that matters directly to homeowners residing by the water: the home is more valuable when the water is clearer (Gibbs, Halstead, Boyle, & Huang, 2002; Moore, Doubek, Xu, & Cardinale, 2020; Papenfus, 2019; Poor, Boyle, Taylor, & Bouchard, 2001). This attribute—water clarity—can be measured in many ways and reflects multiple properties of water (e.g., Hutchinson, 1957; West, Nolan, & Scott, 2015). Brezonik, for example showed that measurements of organic color and turbidity were excellent predictors of Secchi disk depth (Brezonik, 1978). The question for us is, how do we represent water clarity? **Table 5** summarizes the issues for this attribute and the tradeoffs in specifying this quality at any of three levels. All three of these metrics are metrics of water clarity. The metric that is most easily understood—the good, fair, poor categorization—might communicate most effectively, but economists on our Steering Committee told us that they prefer to use a continuous measure in their valuation studies. Similarly, policy makers have told us that they would want to analyze the benefits of changes that might occur within a category, e.g., a 10% improvement in water quality, even if the changes resulted in no change in the category of the water quality classification. We can provide a technical translation to quantify the Secchi disk depth from more basic measures. However, the categorization of water clarity into good, fair, and poor categories requires a social translation. Thus, our goal was to identify metrics that would be most directly relevant to beneficiaries, but with a minimum of social translation embedded. Fortunately, even when a metric of the right attribute may not be directly understandable by a beneficiary, it may still be useful in policy analysis if it is a description of the right attribute.

Table 5. Possible Metrics of Water Clarity

Metric(s)	Measurement Units	Advantages	Disadvantages
Turbidity or Color	FTU or NTU Pt or pcu	Can be predicted directly by quantitative models and thus can be included in linked quantitative management models	Requires the most technical explanation to make relevance clear to many beneficiaries
Secchi disk depth	Meters or Feet	Can be predicted directly by quantitative models and thus can be included in linked quantitative management models	Requires minimal technical explanation to make relevance clear to many beneficiaries
Good, Fair, or Poor	Categories	Categories communicate effectively. When category status can be predicted from biophysical measures, can be used in linked management models	Requires the least technical explanation to make relevance clear to many beneficiaries, but classification must reflect beneficiary values. Translation from biophysical measures to categories may vary over time and space. Doesn't allow for evaluation of policies when changes may occur within a category.

This example is for water clarity, but the same advantages and disadvantages exist for other sets of metrics, for example, pathogen concentrations vs. compliance with regulatory standards for pathogens; lists of macroinvertebrate taxa vs. Multimetric Index of Biotic Integrity (Stoddard et al., 2008) or ratios of observed taxa to expected taxa (Hawkins, Norris, Hogue, & Feminella, 2000; Moss, Furse, Wright, & Armitage, 1987); or good, fair, or poor categorization relative to some ecological baseline.

2.5 Step 5: Data Sources and Availability at Regional or National Scales

When considering the availability of data to quantify or represent the metrics, ecosystem teams recognized that local data would often exist (e.g., a report on the fishing at a local tackle shop or a description of the landcover of local farms). For strictly local applications, these data are the most appropriate to use even if they are not consistent with data from other locations. However, when locations are compared or when regional and national analyses are at issue, more extensive data are necessary.

Extensive data for large regions can come from several different sources. Our tables list the sources identified by each ecosystem team, but in general, these fall into four types of sources:

1. **Direct observation of features of interest in a sampling design that allows for extrapolation to a region of interest.** Such data exist for aquatic ecosystems in EPA's NARS program (U.S. EPA, 2020) (NARS include the National Coastal Condition Assessment, U.S. EPA, 2015; the National Lakes Assessment, U.S. EPA, 2016a; the National Rivers and Streams Assessment, U.S. EPA, 2016b; and the National Wetland Condition Assessment, U.S. EPA, 2016c) and for forests in the USDA Forest Service FIA program (Olsen et al., 1999; Oswalt, Smith, Miles, & Pugh, 2019; Stevens Jr & Olsen, 2004).
2. **Compilations of large amounts of existing data.** For example, the EPA Water Quality Portal (https://www.epa.gov/waterdata/water-quality-data-wqx) and the USGS National Water Information System (https://waterdata.usgs.gov/nwis). These are essential repositories for many analyses and are tempting for use in regional analysis. However, given their lack of a design basis, these sources should not be considered to be a useful source for regional analysis. Such compilations of existing data have been shown to be an inefficient way to make regional estimates and may lead to conclusions completely opposite from conclusions one would draw with data designed for this purpose (Paulsen, Hughes, & Larsen, 1998; Peterson, Urquhart, & Welch, 1999). Further, users of such data will also want to ensure that they understand whether the levels of consistency of data collection and analysis in the data they may extract from such sources matches the needs for consistency in their application.
3. **Remote sensing data.** To the extent that remote sensing can provide estimates of FEGS, it is an invaluable source. In some cases, for example, with the FIA, remote sensing determines the boundaries within which field observations are implemented.
4. **Spatial interpolation models.** These combine extensive data with field observations in sampling programs to produce estimates for the population of resources in a region or even for estimates of the status of a metric at all locations of a resource (e.g. Fox, Hill, Leibowitz, Olsen, & Weber, 2016; Hill et al., 2017). This type of source is useful where complete coverage, rather than population estimates, is required.

These four categories are described in terms relevant to national and regional analysis, and focus on Federal sources of data. In many instances, ecosystem experts also identified state sources of data (e.g., state data on fish in lakes). These can be invaluable sources of information on FEGS for many purposes, but because of different definitions and methods, they may not aggregate well quantitatively to a national or regional picture.

In contrast to the first type of source (designed direct observation), which produces population estimates of ecosystem resources, the third and fourth source types (remote sensing and spatial interpolation models) can provide spatially explicit and extensive representations of ecosystem resources. Spatially explicit representations are important for economic analyses where understanding the local abundance and scarcity of resources is critical to valuation and mapping, which are in turn important for communication and planning. Therefore, ecosystem experts were asked to specify whether the available metrics could be represented in such a manner. Answers to this question are provided in the extensive table in the Appendix under the headings

"Currently described over large areas via remote sensing?" and "Existing capacity to model over large extents?"

In addition to specifying the data source for the available metric, ecosystem experts also described the spatial and temporal scale of the data used. By spatial scale, we mean the spatial extent of the data. Temporal dimensions cover the frequency or the temporal extent of the data. We did not generally address a complementary and important question; specifically, what are the spatial dimensions of the ecosystem features directly used, appreciated, or enjoyed by a beneficiary? However, it is reasonable to expect that the temporal and spatial perspective of the FEGS metric can matter to beneficiaries. The biophysical metrics reported in the metric tables in the Results section are generally provided without a temporal or spatial unit specification. They do not reflect spatial or temporal variation in FEGS metrics or how beneficiaries' interest and interactions with nature may change. Ideally, metrics should be based on data that reflects when and where the FEGS benefits are received, not necessarily as annual averages or as a sample during an ecologically important index period.

An example of the "when" can demonstrate the importance of the timing of the FEGS metric. A swimmer at a Lake Michigan beach, for example, cares more about the water temperature in July than in January (when they are unlikely to be swimming). Likewise, a Midwestern farmer may care less about a winter flood of floodplain farmland than a flood at planting or harvest time, which could endanger the crop. These examples illustrate the need to specify the temporal dimensions of ecosystem services from the perspective of the beneficiary.

These examples relate to the units of individual observations, but of equal importance is the reporting extent. For some uses, the status of an individual stream location is relevant. For other decisions, the relevant scale is the status of individual resources over a region. This report lists sources of information that may be available for large regions or for the nation, which is the scale at which national policies are formed. Those national policies may, for example, include decisions about the allocation of funding to specific resources (e.g., aquatic ecosystems as opposed to highway safety), specific stressors (e.g., riparian habitat as opposed to nutrients) or to specific locations. The allocation of resources over a larger extent is likely to have strategic value in the allocation of resources made by a different group of people. For example, an individual home or property owner might choose to act due to the status of an individual resource. In contrast, a governmental authority might make decisions on the status of resources over a regional or national scale.

In addition to these categories of data, there is an abundance of data on human activity that is closely dependent on ecosystem status. This includes the National Survey of Hunting and Fishing, various surveys of recreational fishing catch and effort (https://www.fisheries.noaa.gov/recreational-fishing-data/types-recreational-fishing-surveys), and the National Census of Agriculture (https://www.nass.usda.gov/AgCensus/index.php). These sources are generally a source of surrogate metrics, e.g., fish landings (a measure of human activity directly dependent upon ecosystem abundance) rather than fish in the water (a FEGS for some beneficiaries), although they may contain some data on FEGS in some instances.

2.6 Example Data Visualizations

Each ecosystem subsection in the Results features one or two data visualizations of a FEGS metric for a particular beneficiary. These visuals are examples of the metrics that may be used to express the interest of the particular beneficiary. Metrics can be continuous or categorial in nature, but the usage of these forms differs.

- **Continuous Metrics.** These are quantitative metrics (including count metrics) that may be displayed directly or binned into ranges first. Metrics with continuous units are best for social science or economic analysis and are common in the economic literature. For example, in a revealed preference example, Netusil, Kincaid, & Chang (2014) showed that house sales prices vary as function of *E. coli* concentrations, dissolved oxygen, temperature, total suspended solids, and pH in two streams near Portland, OR. The magnitude of the effect varies as a function of distance from the streams. They also showed a seasonal effect, where dry season (May to October) *E. coli* levels had a more significant and negative effect on house prices than wet season levels.
- **Categorical Metrics.** These are qualitative metrics (e.g., poor, fair, good, excellent), although they may be based on underlying quantitative data. These are more useful for communication. Biophysical scientists can represent continuous data as categories or grades. These categories reflect ecological conditions, especially as delineated in Stoddard et al. (2006); regulatory standards; or an array of other reasons to communicate and represent data in compelling ways.

The lesson that we drew from this is that the form of the metric used should vary depending on the specific needs of the user. Thus, what we list as FEGS metrics in our tables is one metric that represents something a beneficiary directly uses, appreciates, or enjoys, but for any particular application, the analyst may choose to use the metric in a different form.

3. Results

This section presents the biophysical metrics for each of the seven ecosystem types considered in this report (**Sections 3.1** to **3.7**), as well as a cross-ecosystem synthesis (**Section 3.8**) and a discussion of data challenges (**Section 3.9**). The seven ecosystems are:[1]

- **Section 3.1:** Coral Reefs
- **Section 3.2:** Estuaries
- **Section 3.3:** Lakes
- **Section 3.4:** Rivers and Streams
- **Section 3.5:** Wetlands
- **Section 3.6:** Agricultural Systems
- **Section 3.7:** Forests.

For each ecosystem, a brief summary gives context for the system. A table lists the beneficiaries, attributes, metrics, and data sources chosen for the ecosystem; these table are a subset of the columns in the more detailed tables provided in the Appendix. The text that follows walks through the steps outlined in **Section 2** for one or two beneficiaries and attributes; the intent is to illustrate the process, not to describe every metric. Each ecosystem section also includes one or two example FEGS metric visualizations related to the metrics discussed in the text; these are not the only possible visualizations, but examples to illustrate the approach. The subcaptions note whether the metric visualized is continuous or categorical.

[1] The names of the ecosystem experts who contributed to each section are listed at the beginning of each subsection along with a brief affiliation; see the title page for more detailed affiliations.

3.1 Coral Reefs

Deborah Santavy and Christina Horstmann
U.S. EPA Gulf Ecosystem Measurement and Modeling Division

Photo: Recreational scuba divers enjoy many of the benefits coral reef ecosystem goods and services provide. Photo credit: Christina Horstmann.

Coral reefs are underwater ecosystems comprised of large structures build by reef-building corals (Spalding, Ravilious, & Green, 2001). Thousands of live coral polyps build calcite reefs that are inhabited by at least 25% of the world's marine species, although they occupy less than 0.1% of the area of the world's oceans (Spalding et al., 2001). People frequently visit coral reefs to experience their beauty, extensive biodiversity, and the vast refugia providing habitat for many species of fauna and flora. Many more people enjoy reefs vicariously by viewing the colorful marine organisms via television and social media. Since the invention of scuba, recreational divers and reef visitors have traveled to experience paradise underwater, generating an estimated $36 billion globally in economic activity, and $2.4 billion in the United States alone (Spalding et al., 2017), thereby sustaining local, state, and Territorial economies. Other important recreational services enjoyed by visitors are snorkeling, kayaking, boating, and recreational fishing.

Coral reef ecosystems provide a multitude of benefits to reef visitors (e.g., divers and snorkelers) and residents of adjacent areas that contribute to their well-being, and these are not limited to recreation. Other important ecosystem goods and services provided by reefs include coastline protection from ocean storms and floods, subsistence fishing, sense of place, and cultural way of life for local and indigenous peoples. Visitors and residents alike benefit from tourism opportunities, food products, aquarium fish, jewelry and curios, personal use products, and unique pharmaceutical drugs. Coral reef organisms have proven to be important sources for the development of bioactive products used to treat illnesses and other health problems. Protection of these benefits and the ecosystem that provides them is an important objective for coral reef managers. Currently, coral reef ecosystems are threatened by rapidly increasing coastal human populations; climate changes such as increased sea temperatures and ocean acidification; and the addition of detrimental substances dumped into watersheds and coastal waters.

Step 1. Ecosystem Delineation

Many reefs regarded to be in the same ecosystem are not self-contained, but they can be separated by adjacent ecosystems such as mangroves and seagrasses. This fact makes coral reef boundaries difficult to delineate compared to, for example, lakes or streams, which are defined by their land-waterbody interface. Coral reefs are open marine systems and very irregular in their distribution. Much like forests and mountain ranges, there can be physical and geochemical barriers that prohibit species flow or crossover between adjacent coral reef ecosystems. Some examples of barriers specific to coral reefs are water depth (ocean trenches, deep channels), currents (regional and oceanic), and temperatures (tropical) (Walker, 2012). The outer edges of the coral reef architecture define the physical boundaries, and generally they do not move due to the sessile nature of reef-building corals. Thus, interpretation of coral reef ecosystem boundaries becomes more difficult when considering reef mobile species, especially fish. The fish, and even planktonic larvae, can swim to other reefs considered as the same coral reef ecosystem, but they must past through other ecosystems to get to the next coral reef patch. Coral reefs are limited in their distribution, and they require warm, oligotrophic waters. These limitations restrict the distribution of coral reefs to the tropical oceans. Unlike lakes, rivers, and streams, the coral animal deposits, as its skeleton, the underlying calcium-based reef structure of a coral reef, and larva have specialized preferences that dictate where they will settle.

Boundary delineations for coral reefs can be complicated and uncertain unless considerable effort has gone into using sophisticated mapping techniques to define reef edges and determine where live coral reefs are located (NOAA, 2017). NOAA's U.S. coral reef maps were used to delineate tropical coral reefs in the United States and its territories. The NOAA coral reef benthic maps have limitations because they are based primarily on seafloor topography and have constrained ability to predict where live coral reefs are located. This approach lacks the ability to decipher the difference between dead geomorphic reef structures and living coral reef environments. A second generation of NOAA maps have improved delineation of reef boundaries after allowing time for considerable ground-truthing by research divers, remotely operated vehicles, and underwater cameras. Currently, these second-generation maps provide the best resource by providing coarse resolution where reefs are located, but they continue to be improved by commercial satellite imagery.

Even though there is a dilemma for determining coral reef edges and boundaries with adjacent ecosystems such as mangroves, seagrass beds and the open ocean, the goods and services provided are usually limited to the reef area. An exception is coastal property owners, one beneficiary group that does not utilize the reef area directly. There are many intermediate ecosystem goods and services involved in how coral reefs provide coastal protection, such as wave attenuation provided by reef height and coral morphology. Most of the time, the coral reef boundary and adjacent ecosystems are far from the shoreline, at distances ranging from meters to kilometers.

Step 2. Beneficiary Specification

The coral reef team selected 11 beneficiaries from the NESCS Plus classes that directly benefit or interact with coral reef ecosystems; these represent a diverse and broad spectrum of beneficiaries that interact with most FEGS that coral reefs provide (**Table 6**).

Table 6. Available FEGS Metrics for Beneficiaries of Coral Reefs

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Aquaculturists	Coral Nurseries	Water	Water quality	Turbidity: FTU and NTU ppm. Visibility: m. Satellite chlorophyll a: relative concentrations. Light penetration: Kd, PAR	NOAA: satellite, monitoring by nursery owners	No	No
				Coliforms, enterococci , vibrios (CFUs). Microbial toxins, heavy metals and chemicals: µmol/L)	Local beach water quality, NOAA, monitoring by nursery owners	No	Yes
				Temperature	NOAA	Yes	Yes
		Flora	Flora community	Abundance	Observational surveys by nursery owners	No	No
		Soil/Substrate	Substrate quantity	Percent uncovered	Monitoring by nursery owners	No	No
			Substrate quality	Reef type	Monitoring by nursery owners	No	No
Pharmaceutical and Food Supplement Suppliers	Bioprospectors	Fauna	Commercially important fauna	Diversity, Richness, and Abundance	Published Literature, EPA, NOAA, State	No	No
			Edible fauna		Published Literature, EPA, NOAA, State	No	No
			Medicinal fauna		Published Literature, EPA, NOAA, State	No	No
		Flora	Commercially important flora	Diversity, Richness, and Abundance	Published Literature	No	No
			Edible flora		Published Literature	No	No
			Medicinal flora		Published Literature	No	No
	Extractors	Fauna	Medicinal fauna	Abundance, size, species	Published Literature, EPA, NOAA, State	No	No
			Commercially Important fauna	Abundance, size, species	Published Literature, EPA, NOAA, State	No	No
		Flora	Medicinal flora	Abundance, size, species	Published Literature	No	No
			Commercially Important flora	Abundance, size, species	Published Literature	No	No
		Soil/Substrate	Substrate quantity	Habitat type	Published Literature, benthic habitat maps	No	No
			Substrate quality	Habitat type	Published Literature, benthic habitat maps	Yes	Yes

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Timber, Fiber and Ornamental Extractors	Ornamental Extractors	Fauna	Commercially important fauna	Commercially important live aquarium (species, size, abundance)	Published Literature, EPA, NOAA, State	No	No
				Organisms used for products (species, size, abundance)	Published Literature, EPA, NOAA, State	No	No
		Flora	Commercially Important flora	Commercially important aquarium (species, size, abundance)	NOAA, State, NPS	No	No
				Organisms used for products (species, size, abundance)	NOAA, State, NPS	No	No
Residential Property Owners	Coastal Property Owners	Composite	Extreme events	Probability of Flooding	NOAA SLOSH model, FEMA flood risk maps, EnviroAtlas	No	Yes
			Site appeal	Water clarity	Survey data and satellite	No	Yes
People Who Care	Existence values	Water	Water Quality	Common water quality tests	Local beach water quality, NOAA mussel watch	No	No
		Fauna	Fauna community	Diversity, Richness, and Abundance	Published Literature, EPA, NOAA, State	No	No
		Flora	Flora community	Diversity, Richness, and Abundance	NASA Satellite/ Online Posting, NOAA, State	No	No
		Composite	Ecological condition	—	—	—	—
		Soil/Substrate	Substrate Structure	Reef type, rugosity	NOAA, NASA, Coast Guard, local shops	No	No
		Composite	Site appeal	Field crew opinion, Secchi depth, algal abundance	Word of mouth, local bait and tackle shops, local radio and TV fish reports	No	No
Boaters	Kayakers, SUPs, and Boaters	Fauna	Charismatic fauna	Species, size, abundance, diversity	U.S. FWS, NOAA, State fisheries departments (FWC)	No	Yes
		Composite	Site appeal	Field crew opinion	Word of mouth, local bait and tackle shops, local radio and TV fish reports	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Waders, Swimmers, and Divers	Scuba Divers and Snorkelers	Water	Water quality	Diver recorded visibility	Online posting; diver recorded visibility; NOAA Satellite	No	No
				Common water quality tests	Local beach water quality, NOAA mussel watch	No	No
		Fauna	Charismatic fauna	Presence/absence of charismatic fish	EPA, NOAA, State	Species specific	Yes
			Fauna community	Fish biomass, size, abundance, diversity, richness, species name, feeding guilds, species description	EPA, NOAA	No	Yes
				Coral species name, morphotype, abundance, size (cm), health, rugosity	EPA, NOAA	No	Yes
		Flora	Charismatic flora	Algal abundance, species name, size, density, % cover	Published literature	No	Yes
			Flora community	Invasive species presence/absence, density, taxa, extent, presence	NASA Satellite / Online Posting, NOAA, State	Yes	Yes
		Soil/Substrate	Substrate quality	Reef structure (reef type, rugosity)	EPA, NOAA	No	No
		Composite	Site appeal	Local Reports	Online Posting	No	No
Anglers (Recreational)	Catch-and-Release	Composite	Site appeal	Local reports	Online Posting	No	No
		Fauna	Fauna community	Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Soil/Substrate	Substrate quality	Local reports	Online Posting	No	No
		Fauna	Charismatic fauna	Presence/ absence	State, Federal	No	Yes
	Catch-and-Eat	Fauna	Fauna community	Conc. of pathogens/ toxins/ Contaminants/ parasites in fish	FDA, USDA	No	Yes
		Fauna	Fauna community	Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Soil/Substrate	Reef Structure	Local reports	Online Posting	No	No
		Fauna	Taxa	Presence/ absence	State, Federal	Yes	Yes
		Composite	Site appeal	Local reports	Online Posting	No	No
Food Subsisters	Anglers (Subsistence)	Edible Fauna	Edible fauna	Presence/ absence	State, Federal	Yes	Yes
		Fauna	Fauna community	Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Soil/Substrate	Substrate quality	Local reports	Online Posting	No	No
		Fauna	Fauna community	Conc. of pathogens/ toxins/ Contaminants/ parasites in fish	FDA, USDA	No	Yes

Step 3. Attribute Specification

For coral reefs, we selected scuba divers and snorkelers (subsequently referred to as just divers) as the beneficiary of interest to demonstrate the FEGS framework and apply standardized language from Table 4 when selecting attributes to describe the biophysical components of FEGS metrics. For this beneficiary, the primary attribute is the water itself. The sub-attributes for water are the water quality, quantity, and movement. These attributes influence how a diver interacts with and experiences the underwater coral reef environment. One key specific attribute is water clarity (under the sub-attribute water quality), which is of great interest to divers and snorkelers. Water clarity is vital for the divers to see and experience coral reefs and is linked to the ability to experience the coral reefs and associated fish communities. Unfortunately, water quality for coral reefs can often be quite variable depending on the location, season, time of day, ocean conditions, and weather. There are few long-term databases at regional or national scales for water clarity of coral reefs, because it is so variable over large spatial scales.

Divers care directly about many other specific attributes for water quality, for example the presence of harmful contaminants and high pathogen concentrations (see Table 4 for more specific attributes analyzed). Exposure to harmful materials or microorganisms is potentially dangerous since divers and snorkelers are immersed in the water and may also ingest seawater accidentally. Many states, territories, counties, and municipalities regularly monitor and report this information as part of water quality reporting requirements for treated wastewater and U.S. EPA programs under the 2000 BEACH Act (Beaches Environmental Assessment and Coastal Health Act, Public Law 106-284). Results that identify whether there are health or safety issues with contact or immersion in a particular waterbody are reported to the public by signage, online, and in newspapers. The water quality sub-attributes are of direct interest to all divers and snorkelers, not reserved to just coral reef ecosystems.

The important and unique qualities valued by divers on coral reefs are FEGS metrics representing the presence, abundance, size, and species diversity of the fauna communities. These sub-attributes for coral and fish communities are what attract divers, who hope to see many different colors, textures, and movements on a healthy reef. Other important faunal metrics are the presence and abundance of charismatic species, such as sharks, turtles, dolphins, and large fish. Likewise, the presence of flora community can be important, like charismatic species of bright pink crustose coralline algae as an example of a specific flora attribute. These are usually recorded when seen and reported to others in the area, but their locations usually cannot be predicted in real time and space. Many recreational divers are thrilled with an encounter with one of these species; therefore, availability of these metrics would certainly be preferred by many coral reef recreators when making choices where to dive. Due to the rarity of charismatic species encounters, the main sub-attributes that divers look for are fauna and flora communities.

Divers also experience the environment beyond the species themselves. The reef structure is considered a soil/substrate attribute and categorized as the sub-attribute of substrate quality evaluated by the metric rugosity. Finally, a composite attribute includes the sub-attribute of site appeal, which is the experience and interaction with the underwater viewscape, using all senses (sight, hearing, touch).

Step 4. Metric Specification

For water clarity, the ideal metric is Secchi disk depth because it is easily understood and obtained, reliable, inexpensive, and widely used. Water clarity could also be translated from satellite imagery into Secchi disk depth (Kloiber, Brezonik, & Bauer, 2002).The water clarity metric most commonly referenced in the literature is underwater visibility recorded by individual divers. These estimates are often guided by experience and not usually recorded or made available to other divers. Thus, they are not measured consistently across coral reef locations and can be less reliable and more subjective. Since this is the attribute that divers care the most about, making average monthly visibility reports available to beneficiaries would be especially desirable for divers choosing dive vacation destinations. Other potential metrics for water clarity include chlorophyll *a* measurements and total suspended solids determined by water sampling and satellite imagery. As the ability to model clarity from water quality parameters improves, it will be increasingly derived from satellite data, such as chlorophyll *a*, and made available to the diving public (Kloiber et al., 2002).

For reef structure, desirable geological structures (e.g., high relief, large drop offs, cavernous tunnels) can be very location specific and are always a lure for experienced divers and snorkelers. Other sources for potentially preferred dive sites might be obtained from underwater benthic habitat maps determined by side scan sonar and LIDAR (light detection and ranging) imagery. Usually, spatially explicit data at regional and state levels are not obtained over long-term or regular temporal scales. Closing this gap would require significant changes in monitoring and sampling efforts or a greater attempt to combine localized datasets to report FEGS on regional or national scales.

Metrics deemed most important to the beneficiaries should be monitored consistently over time and at many locations by researchers or environmental departments. Currently, most monitoring programs are designed and used by biophysical scientists evaluating coral reef condition in an ecological context. When more recreational divers communicate what traits they value most, there might be increased efforts to obtain these biophysical data, translate them into reliable FEGS, and communicate them in places where they are easily obtained by the beneficiaries and the public. These actions would be driven by increased public or beneficiary demand.

Step 5. Data Sources and Availability

In **Table A1** of the Appendix, currently available data and the idealized dataset for many of the FEGS metrics for coral reefs are presented. The data sources provided are ones useful for a national or regional audience and for the analysts and policy makers working at that scale. For all beneficiaries, we assume that local data useful to individual beneficiaries making individual decisions may be available. For this ecosystem, we delineate some of those local data sources here and their intersection with national and regional datasets.

Because of the patchy nature of reefs, most of spatial data are very localized and site specific, making it difficult to scale up to greater temporal and spatial scales without a large effort for data organization and FEGS metric communication to the public. After examining numerous datasets, several trends were identified. When a dataset covers a large spatial region, often the data are limited temporally. This might be resolved by incorporating coral reef monitoring and metrics into a national assessment and data program like NARS. Unfortunately, coral reefs are limited to mostly U.S. Territories that are often lower priority when considering budgets and where limited resources will be spent. The monitoring of coral reefs is usually very expensive and time consuming, and many measurements are made using scuba.

The databases we have found that contain the most extensive reef coverage for reefs found in the United States and Territories is accessible online through NOAA’s National Coral Reef

Monitoring Program. These data are suitable for calculating FEGS metrics to be used in analyses that can be appropriately scaled both spatially and temporally to apply the management decision context (NOAA, 2017; NOAA and U.S. Coral Reef Task Force, 2014). The program was designed to report status and trends of coral reef condition and their associated communities. Many of these data have not yet been sufficiently or adequately translated into metrics directly understandable by beneficiaries (especially as discussed in **Section 2.4**, Metric Specification, and **Section 3.9**, Challenges to Providing Data on FEGS), as the implementation of an ecosystem goods and services perspective is relatively novel for overworked coral reef resource managers. This foundational work might initiate interest in utilizing some of the FEGS biophysical metrics to be further translated into more meaningful communications to divers. Future work could utilize these datasets for analyzing metrics to determine useful FEGS indicators that are widely available for multiple beneficiaries using reef ecosystem goods and services.

Example Visualizations for FEGS Metrics in Coral Reefs

The two examples of data visualization for important coral reef metrics are from the Great Barrier Reef in Australia. **Figure 4** illustrates how a metric such as coral cover can be shown on a large spatial scale. This metric is important to scuba diver beneficiaries. **Figure 5** represents our suggested metric for water clarity (Secchi disk depth).

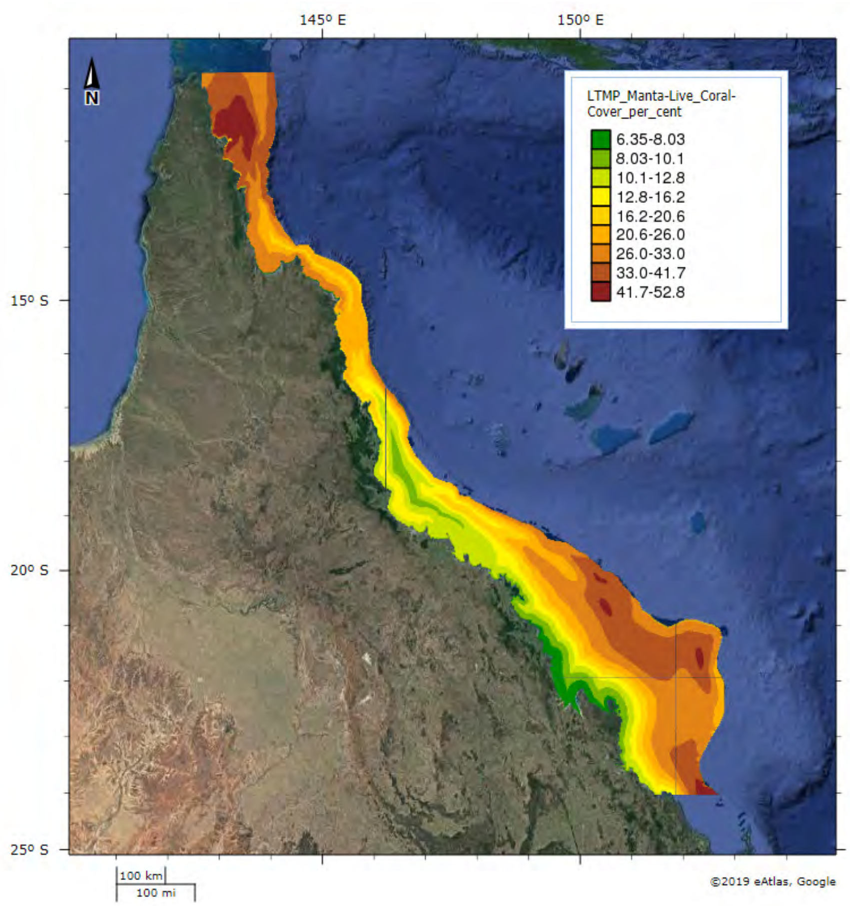


Figure 4. Percent live coral cover on the Great Barrier Reef, Australia.
Percent live coral cover is a metric for many coral reef beneficiaries, e.g., Scuba Divers and Snorkelers as shown in Table 6. This is classified as a continuous metric. Green represents lower coral cover and red represents higher. Source: (AIMS, 2015).

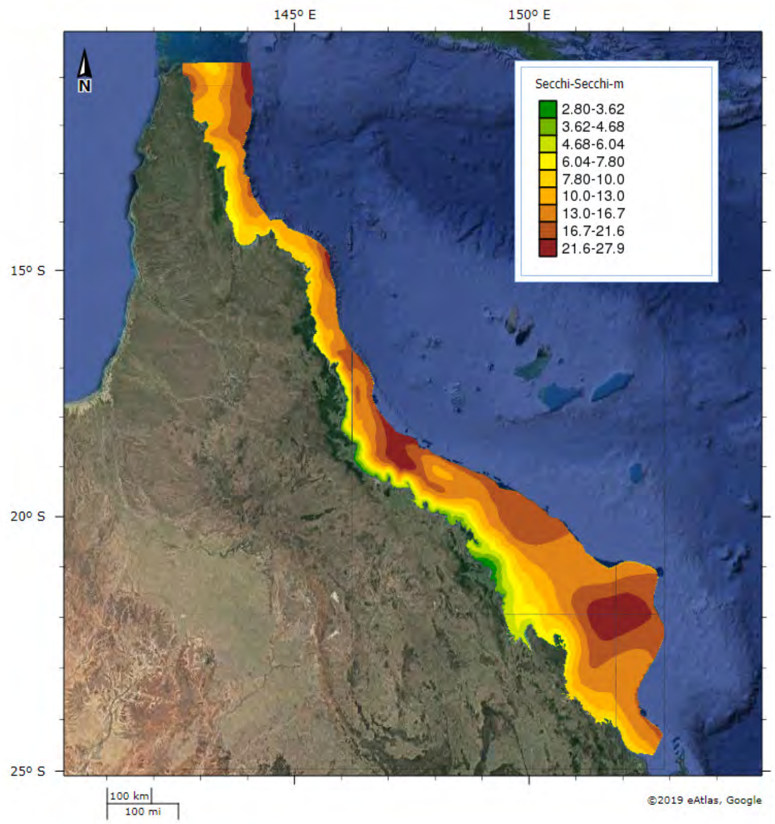


Figure 5. Secchi disk depth for the Great Barrier Reef, Australia, 1992–2006.
Secchi disk depth is a measure of water clarity. This is classified as a continuous metric. Here, green represents lower water clarity and red represents higher (AIMS, 2009).

3.2 Estuaries

Walter Berry and James S. Latimer, U.S. EPA Atlantic Coast Environmental Science Division

Photo: This spot on a small estuary in Rhode Island is popular with boaters and recreational anglers, but is especially popular with kayakers and standup paddleboarders. Photo credit: W. Berry.

Estuaries are where rivers meet the sea. They have long been hubs for commerce, providing sheltered harbors with access to inland areas. Many of the nation's largest cities have grown up around these harbors. Estuaries produce many benefits (or ecosystem services) for people: recreational opportunities; food; storm and flood protection; natural beauty; and important cultural significance to the region. They also support tourism, transportation, and other economic activities, as they have for centuries, and provide support to a broad range of scientific and educational activities.

Coastal counties of the United States are home to over 126 million people, or 40 percent of the nation's total population (NOAA, 2019a [Fast Facts]). Not only do estuaries provide ecosystem services to the people live close to or physically use them, they also help to define the character of a whole region. Examples include the importance of the quahog fishers in Narragansett Bay to the identity of Rhode Island residents or the Chesapeake Bay watermen to the residents of Delaware, Maryland, Virginia, and the District of Columbia.

Step 1. Ecosystem Delineation

An estuary is a partially enclosed body of water with one or more rivers or streams flowing into it upstream and a connection to the open sea downstream. In a modern estuary, the upstream boundary of the estuary is often a dam, above which the water is fresh. Below the dam, the water is brackish, increasing in salinity until it meets the sea. Estuaries in the United States vary in size from tiny creeks flowing into the ocean to the Chesapeake Bay (approximately 4,480 square miles (Chesapeake Bay Program, 2020).

Step 2. Beneficiary Specification

The Estuary team selected nine beneficiaries from the NESCS Plus classes that directly benefit or profit from estuarine ecosystems (**Table 7**). These represent a diverse and broad spectrum of beneficiaries that interact with most FEGS that estuaries provide.

Table 7. Available FEGS Metrics for Beneficiaries of Estuaries

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Aquaculturists	Shellfish Growers	Water	Water quality	Turbidity: FTU & NTU, ppm. Visibility: m. Light penetration: Kd, PAR	NOAA: satellite, monitoring by shellfish growers	No	No
				Coliforms, *enterococci*, *vibrio* (CFUs). Microbial toxins, heavy metals & chemicals	Local beach water quality, NOAA, monitoring by nursery owners	No	No
				Shellfish closures	Local beach water quality, NOAA, monitoring by nursery owners	No	No
				Salinity, Temperature, pH, DO	State, University, NARS	Sea surface temp	No
		Water	Water Movement	Tides, wind speed & direction	Data from meteorological reporting stations & marine buoys, NOAA	No	Yes
		Fauna	Commercially important fauna	Abundance, species	Observational surveys by shellfish growers	No	No
		Flora	Commercially important flora	HAB (outbreak frequency)	Observational surveys by shellfish growers	No	No
				Chlorophyll aChlorophyll *a*	Observational surveys by nursery owners	No	No
		Soil/Substrate	Substrate quantity	Permitted area	Municipal records	No	No
		Fauna	Commercially important fauna	Shellfish closures due to disease organisms	Monitoring by shellfish growers, State postings	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Commercial Anglers	Commercial Anglers	Water	Water movement	Tide, surge, wind speed & direction	NOAA, Weather channel	Yes	Yes
				Wave height, speed & direction	NOAA, Weather channel	Yes	Yes
		Atmosphere	Wind strength/speed	Wave height, speed & direction	NOAA, Weather channel	No	Yes
		Fauna	Fauna community	Presence/ absence	State, Federal	Yes	Yes
				Conc. Of Pathogens/ Toxins/ Contaminants/ Parasites	FDA, USDA, State	No	Yes
				Hazardous Species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Soil/Substrate	Substrate quality	Local reports	Online Posting	No	No
		Water	Water movement	Tide, surge, wind speed & direction	NOAA, Weather channel	Yes	Yes
Pharmaceutical and Food Supplement Suppliers	Extractors/ Bioprospectors	Fauna	Medicinal Fauna	Abundance, size, species	Published Literature, EPA, NOAA, State	No	No
			Commercially Important Fauna	Abundance, size, species	Published Literature, EPA, NOAA, State	No	No
			Fauna community	Diversity, richness of extractable source	Published Literature, EPA, NOAA, State	No	No
		Flora	Medicinal Flora	Species Abundance, size, species	Published Literature	No	No
			Commercially Important Flora	Species Abundance, size, species	Published Literature	No	No
			Flora community	Species Diversity, richness of extractable source	Published Literature	No	No
Residential Property Owners	Coastal Property Owners	Composite	Extreme events	Probability of flooding	FEMA Maps and EnviroAtlas	No	Yes
			Site Appeal	—	—	No	No
Transporters	Barge or ferry	Water	Water movement	Local/ Regional currents	Data from meteorological reporting stations & marine buoys, NOAA	Yes	Yes
			Water movements	Water intensity	Data from meteorological reporting stations & marine buoys, NOAA	Yes	Yes
			Water quality	Nautical Hazards	NOAA charts	No	Yes
		Atmosphere	Wind strength/speed	Wind intensity	Data from meteorological reporting stations & marine buoys, NOAA	No	Yes

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
People Who Care	Existence	Composite	Site appeal	Field crew opinion	Word of mouth, local bait & tackle shops, local radio & TV fish reports	No	No
			Ecological Condition	—	—	—	—
		Water	Water quality	Common water quality tests	Local beach water quality, NOAA mussel watch	No	No
		Fauna	Fauna community	Diversity, Richness & Abundance	Published Literature, USEPA, NOAA, State	No	No
		Flora	Flora community	Diversity, Richness & Abundance	NASA Satellite/ Online Posting, NOAA, State	No	No
		Soil/Substrate	Substrate quality	Shoreline Type	NOAA, NASA, Coast Guard, local shops	No	No
Boaters	Kayakers, SUPs, and Boaters	Fauna	Charismatic Fauna	Species, size, abundance, diversity	U.S. FWS, NOAA, State fisheries departments (FWC)	No	Yes
		Composite	Site appeal	Field crew opinion	Word of mouth, local bait & tackle shops, local radio & TV fish reports	No	No
Anglers (Recreational)	Catch-and-Release	Fauna	Charismatic fauna	Presence/ absence	State, Federal	No	Yes
			Fauna community	Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Composite	Site appeal	Local reports	Online Posting	No	No
	Catch-and-Eat	Fauna	Fauna community	Presence/ absence	State, Federal	No	No
				Conc. of pathogens/ toxins/ contaminants/ parasites	FDA, USDA, State	No	Yes
				Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes
		Composite	Site Appeal	Local reports	Online Posting	No	No
Food subsisters	Anglers (Subsistence)	Fauna	Fauna community	Presence/ absence	State, Federal	No	No
				Conc. of pathogens/ toxins/ contaminants/ parasites	FDA, USDA, State	No	Yes
				Hazardous species Presence/ absence	Beach Flags, Online Posting	No	Yes

Step 3. Attribute Specification

For estuarine systems, we selected anglers as the broad beneficiary group to demonstrate the FEGS Framework methodology for attribute selection. Within this category, we include commercial, recreational (catch-and-release and catch-and-eat), and subsistence anglers. These attributes are drawn from the standardized list in Table 4 and are used to describe the biophysical attributes of FEGS metrics.

For this beneficiary group, the primary attribute is the fish community, which is first listed as the fauna in the attribute category. Different types of anglers care about specific types of fish communities; these important distinctions are described in the subattribute column as edible fauna, keystone fauna, charismatic fauna, or commercially important fauna. The degree to which the attribute is more important to the specific beneficiary likely relates to the degree of dependence the angler has on the fish—for example, are the fish the primary source of sustenance or revenue, or a weekend recreational activity? Commercial, subsistence, and recreational catch-and-eat anglers care about whether the type of fish are edible and safe to eat (i.e., free of tissue contamination); catch-and-release anglers likely do not. Anglers who are not dependent on the fish biomass for food or profit also typically consider the whole experience of fishing—the sights, sounds, and smells and so are more likely to care about site appeal (is the fishing location pleasant to the senses?) than commercial or subsistence anglers. This important sense of place and personal experience is accounted for in the composite attribute category with site appeal as the specific subattribute. Commercial fishers also care about tides and waves (subattributes of water categorized as water movements) and related atmosphere attributes of wind speed and strength, which can also affect wave intensity and direction.

Step 4. Metric Specification

This metrics discussion focuses on the interests of recreational catch-and-eat and subsistence anglers. These anglers care about the specific fish species, abundance, and size, which are FEGS metrics described below. These considerations are generally similar for both those harvesting finfish and those harvesting shellfish.

Anglers need information on abundance, species, and size to be very specific for it to be useful. Fishing success can vary tremendously with location, season, time of day, or the tide. This sort of specific information used to be available only from local sources like bait shops and newspapers but is now more available on the internet due to newsletters and listservs (e.g., from the Rhode Island Saltwater Anglers Association) and apps (e.g., Fishbrain). Information on contamination of fish is available on a local level, although it will usually be in the form of fish advisories (e.g., “Don’t eat the fish if you are a nursing mother or a small child.”). Information on the appeal of fishing sites is likely to be only available from places like bait shops.

Most of the fisheries data available for estuaries are collected by and for fishery biologists and managers. Managers are not as interested in local data as anglers are. They typically collect data on larger scales—statewide or beyond. These data are more in line with the scales of the management questions they work with, such as

> “Will we exceed our state quota for a particular species?”
> “How is the stock doing (is it increasing or decreasing)?”
> “Should we tighten or loosen restrictions on a particular fishery?”
> “What is the economic benefit of recreational fishing to my state?”

Some data are available on the actual abundance of individual species in estuaries, but for the most part, the available data relates to juveniles caught in seines or bottom fish caught in large bottom trawls, which is of little use to anglers and may only be available by special request (e.g.; Rhode Island Department of Environmental Management [RIDEM] juvenile flounder data; Anna Gerber Williams [RIDEM], personal communication). These data are, however, useful for looking at long-term trends in various fisheries and predicting what the stocks will do in the future. By contrast, a lot of data are available on the numbers and weights of fish harvested in estuaries. These data are usually reported on a scale useful for management, but not useful for most recreational anglers, and do not represent a FEGS because of the effort component in catch data. Further complicating matters from an estuarine perspective is that estuarine fisheries are often lumped with fisheries data from areas farther offshore.

Thus, the currently collected data are of a type more useful to fisheries managers than individual anglers, and the continued monitoring of even those data may be imperiled by budget cuts. The rapidly changing climate means that long-term data sets are more important than ever to provide context on observed changes in fish abundance and species composition, but these may not be predictive of what will happen in the future. Recreational anglers would benefit from more site-specific information. This may be easier for shore anglers, because access is limited in many areas, although some fishing charts are available for those fishing from a boat. To be really useful, the information must be season- and species-specific. For example, a given dock or bridge may be a great spot for squid or young-of-the-year bluefish at certain times of the year but be virtually useless for fishing at other times of the year.

Information about tissue contamination is generally available in the form of fish advisories for those species that are harvestable. Often the information is site specific, with postings that a certain area is closed to fishing or shellfishing. Shellfishing advisories are often conditional, with certain areas being closed after rainfall.

Site-specific information on site appeal is not generally available for estuaries. It may also be that this attribute is not as important as it is in some other ecosystems (e.g., lakes and streams) because estuaries are generally more open and developed than other ecosystems.

Some of the recreational catch data that could make an available metric are already collected (NOAA, 2019b [Recreational Fishing Data]). However, catch data are only surrogates for FEGS. The FEGS is the abundance of fish in the water. Fish landings depend on the abundance of fish in the water, but are also a measure of human activity along with site access, technology, and skill (Maunder et al., 2006).

Step 5. Data Sources and Availability

Much of the available fisheries data are collected on a regional scale and are designed to be scaled up to a national scale, like NOAA’s Marine Recreational Information Program (NOAA, 2020a [About the Marine Recreational Informational Program]). Other data are collected on a state scale, like RIDEM’s Narragansett Bay Juvenile Finfish Seine Survey (RIDEM, 2019), and scaling these data up to regional or national scales may be more difficult because of the different methodologies used from place to place. As stated above, much of these data (e.g., NOAA’s Marine Recreational Fishing Information Program; NOAA, 2020a) are catch data, which are only surrogates for FEGS; only some of the available data are actual “numbers of fish in the water” data (e.g., Narragansett Bay Juvenile Finfish Seine Survey; RIDEM, 2019), which directly measure the FEGS.

Most of the metrics selected for this project were drawn from the National Coastal Condition Assessment (U.S. EPA, 2015), a project that periodically surveys the nation's estuaries. The sampling for this assessment is based on more than 1,100 independent samples from five regions of the country, representing the variation in estuary condition. Each site is sampled once, between June and September. This sampling is repeated every five years; the most recent publicly available dataset is the 2010 sampling data; results from the 2015 survey are expected in 2020. Results are generally pooled into annual means and seasonal averages are not available, which may impact some beneficiaries, like swimmers, who likely care more about summertime water temperature highs and lows.

Example Visualizations for FEGS Metrics in Estuaries

For both recreational and commercial anglers, the key FEGS is "Faunal Community", actual fish in the water. Figure 6 shows two datasets for Winter Flounder and American Lobster in Naragansett Bay. Figure 6a is an example of data representative of the actual FEGS (abundance of American Lobster and Winter Flounder), because it was taken using a standard trawl, from a single site in Narragansett Bay. These data might not be as useful to a fishery manager but might be more useful to someone looking to target fish in Narragansett Bay.

However, as is discussed above, most of the available data on faunal abundance of fish in estuaries that would be of interest to recreational and estuarine anglers is actually catch data, which are only surrogates for fish abundance, because they are confounded by level of effort. Most of these are also collected on a large scale, appropriate for regional fish stock assessment. Figure 6b, taken from NOAA landings, is an example of this sort of data. It shows the poundage of American Lobster and Winter Flounder caught in Rhode Island from 1950–2012.

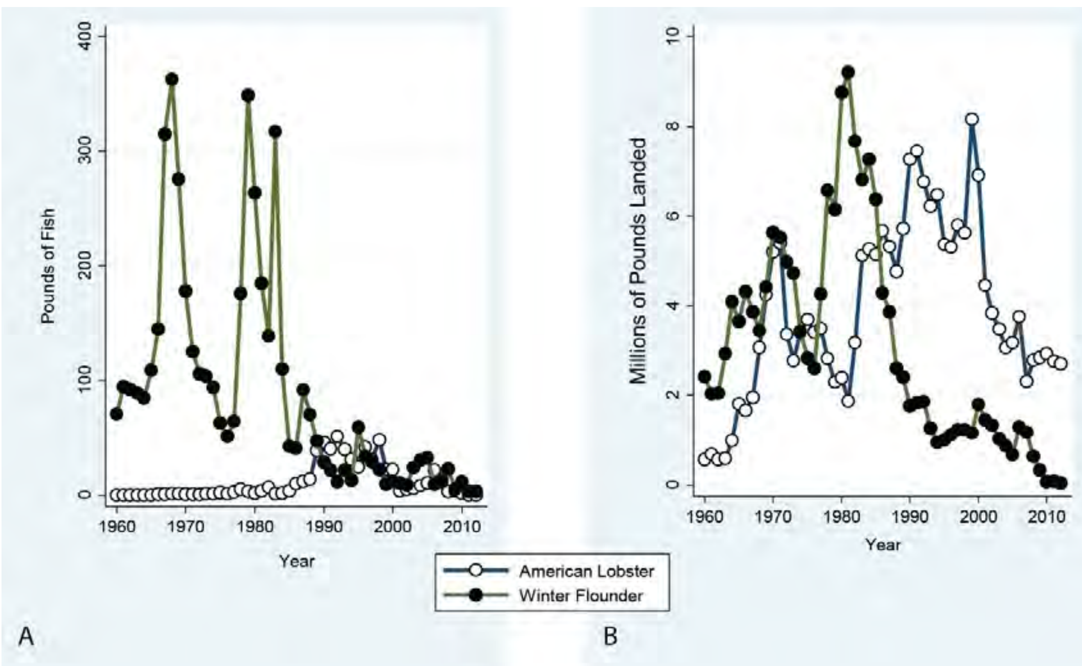


Figure 6. Winter Flounder and American Lobster (a) captured in an individual trawl at a single station in Narragansett Bay, and (b) landed and brought to the docks in Narragansett Bay.
The single trawl (a) is a measure of organism levels in the water at a point in time and space. If the methods are consistent over time, it is a measure of the FEGS over 6 decades at that single location. The brought to docks (b) is a measure of an economic good, which is dependent on the FEGS as well as the effort of commercial anglers aggregated over each year and the entire Bay. These are both example of continuous metrics

3.3 Lakes

Ted R. Angradi, U.S. EPA Great Lakes Toxicology and Ecology Division

Photo: Lakes provide many important ecosystem services to a variety of beneficiaries. For recreational boaters, enjoyment of the water and the setting are important contributions from nature. Photo credit: DOI.

Freshwater lakes, reservoirs, and ponds provide many benefits to a variety of users including recreational users such as swimmers, anglers, property owners, farmers, and subsistence food gatherers. Benefits include serving as a source of water for consumptive uses (e.g., irrigation, drinking water, or for cooling), non-consumptive uses such as contact recreation, and non-use existential benefits. Recreational fishing can be either a consumptive use when caught fish are eaten or a non-consumptive use when catch and release is practiced. In many inland and arid areas of the country, lakes and reservoirs are a primary location for outdoor recreation.

There are about 41 million acres of lakes in the U.S. and tens of thousands of lakes in the lower 48 states (U.S. EPA, 2003a). The exact number is surprisingly difficult to describe without extensive qualifications. For example, how does one count the smallest ponds or distinguish temporary water bodies from a lake? In addressing questions such as this, the National Aquatic Resource Surveys (NARS) surveys defined a target population of 159,652 lakes. The NARS surveys (e.g., the National Lakes Assessment [NLA] of 2012; U.S. EPA, 2016a) provide an abundance of data on lakes. In some areas, lakes and ponds provide irreplaceable benefits for specific users. Examples include wild rice in lakes from the upper Midwest and livestock stock ponds (tanks) in the arid west. Reservoirs provide drinking water for many communities including for large cities such as New York City, New York and Boston, Massachusetts (https://www1.nyc.gov/site/dep/water/drinking-water.page, https://www.mass.gov/locations/quabbin-reservoir). Many millions of people depend upon reservoirs and their watersheds as sources of safe drinking water

Step 1. Ecosystem Delineation

How the lake ecosystem is delineated depends on the beneficiary. For anglers, swimmers, and boaters, the wetted perimeter is a reliable boundary for the part of the system that provides benefits. For property owners and non-use beneficiaries, lake benefits may depend on composite attributes of the non-aquatic but closely associated habitats of the lake setting, such as scenic views that including riparian and terrestrial vegetation. For some beneficiaries, the appropriate delineation may overlap with another ecosystem. For example, the lake habitat from which wild rice harvesters derive a benefit may in other contexts be considered wetlands.

Step 2. Beneficiary Specification

The Lakes team selected eight beneficiaries from the NESCS Plus classes that directly benefit or interact with lakes (**Table 8)**. These beneficiaries include consumptive and non-consumptive users of lakes.

Table 8. Available FEGS Metrics for Beneficiaries of Lakes

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Residential Property Owners	Lakeshore Property Owners	Composite	Site Appeal	Appealingness score (1-5 scale)	EPA National Lakes Assessment	No	No
		Flora	Flora Community	Presence/absence of nuisance species, total macrophyte abundance (0-4 scale)	EPA National Lakes Assessment	No	No
People Who Care	Existence values	Fauna	Fauna Community	Macroinvertebrate MMI score (0-100), or condition class (good, fair, poor)	EPA National Lakes Assessment	No	No
		Composite	Site appeal	Pristineness (1-5 scale)	EPA National Lakes Assessment	No	No
Boaters	Power Boaters	Water	Water quality (clarity)	Secchi depth (m)	EPA National Lakes Assessment	Yes	No
		Flora	Commercially important flora (nuisance species presence)	Coverage (%)	State Websites	Maybe	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Waders, Swimmers, and Divers	Swimmers	Water	Water movement (waves and currents)	Water currents - Beach hazard warnings (red, yellow, green)	State and local websites	Yes	No
			Water quality (composite)	Swimmability (good, fair, not swimmable)	EPA National Lakes Assessment	Yes	No
			Water quality (clarity)	Secchi depth (m)	EPA National Lakes Assessment	Yes	No
			Water quality (pathogens)	Cyanobacteria concentrations (cells/mL)	EPA National Coastal Condition Assessment	Yes	Yes
				Microcystin concentrations (µg/L)	EPA National Coastal Condition Assessment	Yes	Yes
Anglers (Recreational)	Catch-and-release	Fauna	Culturally important fauna (abundance)	Presence/absence, lake survey, creel survey	State Websites	No	No
	Catch-and-eat	Fauna	Edible fauna (tissue contamination)	Mercury, PCBs, PAHs, concentration (ppb)	EPA National Lake Fish Tissue Study	No	Maybe
				Fish consumption advisories by water body (y/n)	State Websites	No	No
Food Subsisters	Wild Rice Harvesters	Flora	Culturally important flora (wild rice)	Recognized wild rice lake (y/n)	State websites	No	No
				Wild rice area (ha)	Landsat 7	Yes	No
	Anglers (Subsistence)	Fauna	Edible fauna (abundance)	Recruited biomass (kg/ha)	State Websites	No	No

Step 3. Attribute Specification

We selected recreational anglers, specifically, both a catch-and-release and a catch-and-eat angler, as the beneficiary type of interest to illustrate the FEGS Framework methodology. Using this beneficiary, we then selected attributes from the standardized list in Table 4. Both anglers care primarily about the fish community, which is first represented in the attribute table as fauna. The main distinction for these two anglers is whether the fish is caught for sport or for eating. For catch-and-release anglers, who are excited for sport fishing and game fish, the attribute subcategory of interest is therefore charismatic fauna. Catch-and-eat anglers, by contrast, care that the fish are safe to eat, so the attribute subcategory of interest is therefore edible fauna. From these standardized attributes, specific metrics were chosen as the FEGS metric.

Step 4. Metric Specification

Continuing to use the angler as the beneficiary to demonstrate the FEGS Framework, we then selected the best available and ideal FEGS metric. This method and way of thinking was then repeated for each beneficiary. For this beneficiary, the fish community itself is the best metric. These data are likely available from state fish and wildlife agencies, which track these data carefully. Catch-and-eat anglers also care about the safety of eating the fish, notably the presence and concentration of mercury and other chemical or biological contaminants.

Step 5. Data Sources and Availability

No national fish community dataset exists that captures what recreational anglers value; such data are usually available at a state or regional levelm and there are practical barriers to the creation of regional or national metrics of fish FEGS and the angling benefits therefrom. Foremost among these challenges is the lack of consistency of the data across states. For example, all the states bordering Minnesota have some public information that is comparable to that available from that state's *LakeFinder* application, which may be accessed at https://maps1.dnr.state.mn.us/lakefinder/mobile/, but the information varies in completeness and format. It may be possible to compile and standardized the underlying data at a regional or national scale, but that would require a significant effort.

Adding a characterization of fish populations would improve the National Lake Assessment, however, it is unlikely that this will happen. Fish sampling would be expensive, difficult to standardize across lake types, and would likely not be representative of fish species and population characteristics most relevant to recreational anglers. More useful would be an effort to compile available state and tribal fisheries information into ecoregional or national databases from which indicators could be developed.

Example Visualizations for FEGS Metrics in Lakes

Easy to collect metrics for the water clarity attribute of lakes, in particular Secchi depth, may be suitable national- or regional-scale indicators for the assessment of benefits provided by lakes for multiple beneficiaries, like boaters and swimmers. Recent research using data from the National Lakes Assessments (Angradi et al., 2018) showed that the water clarity attribute of lakes varied among regions (**Figure 7**). By using thresholds derived from replicate subjective perceptions of benefit quality, the percent of the lake resource providing each level of benefit could be estimated (Figure 7, inset). Applying these thresholds to future biophysical assessments could provide insight to changes over time in the quality of the lake benefit for contact water users (e.g., swimmers, divers). For the specific attribute of lake currents, which are relevant for the safe enjoyment of the resource by swimmers, there are local or larger scale sources of information on beach hazards. The National Weather Service provide a daily forecast of swim risk for the beaches of the Great Lakes (https://www.weather.gov/greatlakes/beachhazards); an example is shown in **Figure 8**. Data compiled from these daily forecasts could be used to estimate change in the swimming benefit over time in response to climate change or other drivers.

A final example visualization not related to anglers is provided in **Figure 9**, which shows wild rice harvesting licenses sold. The actual FEGS is wild rice area, but those data are not readily available. The sales of licenses is a surrogate that reflects a related human activity.

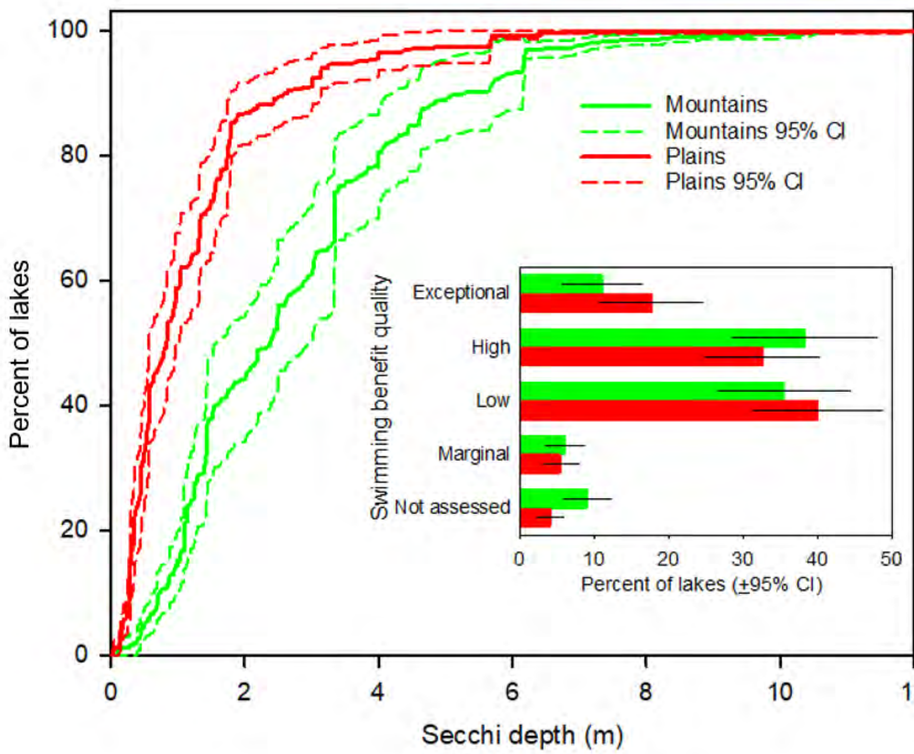
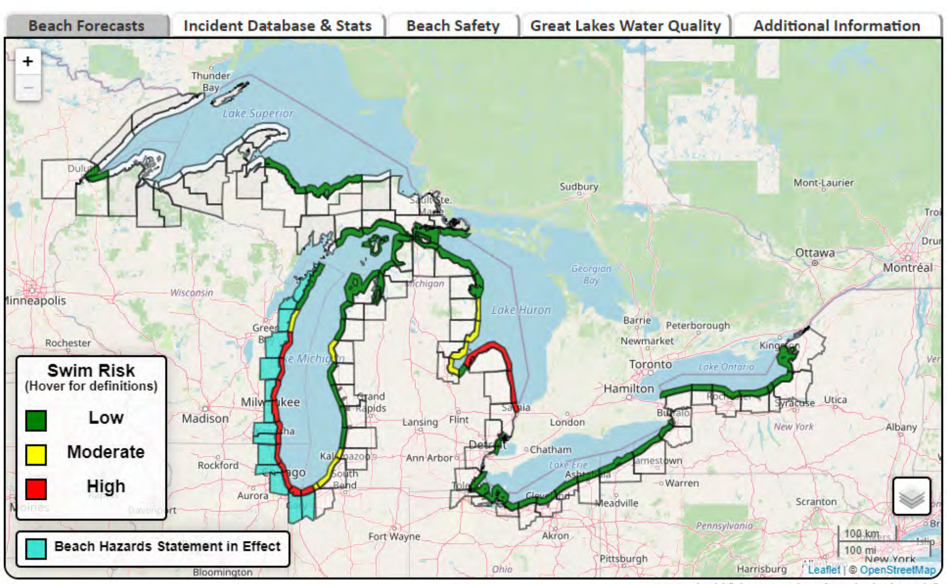


Figure 7. Regional estimates of Secchi depth by ecoregion (2012 National Lakes Assessment).
Main plot shows the cumulative distribution function for each ecoregion. Values on the vertical axis are the percent of lakes with less than or equal the Secchi depth value on the horizontal axis. This is a continuous metric. The inset plot shows the percent of lakes in each swimming benefit quality class based on thresholds derived by Angradi et al. (2018), a categorical metric.



Forecast updated daily between 3 and 5 AM/PM and updated as needed)

Figure 8. Great Lakes Beach Hazard forecast for September 8, 2020.
Swim risk is based on predicted measured wave height and current strength; this is a categorical metric. This resource also provides information on harmful algae blooms in the Great Lakes (Great Lakes Water Quality tab), which is a metric for the attribute of pathogens in water.

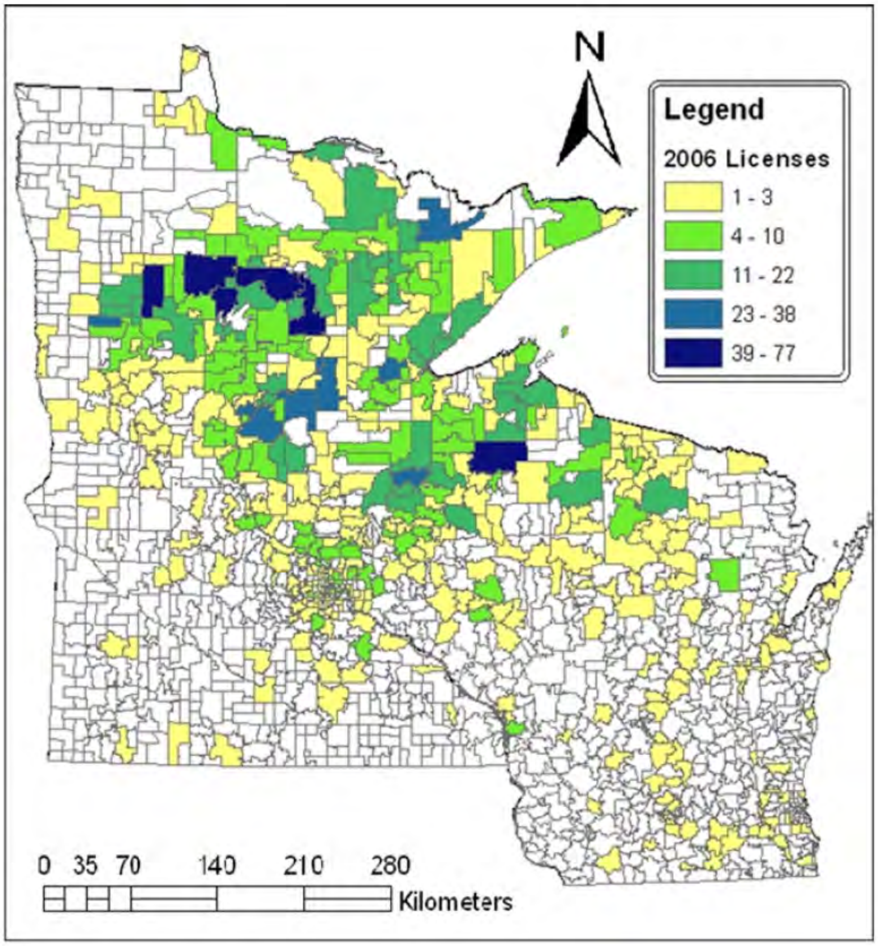


Figure 9. Wild rice harvesting license sales by zipcode combining 2005 and 2006 for Minnesota.
Source: Wild rice area is a measure of a FEGS for wild rice harvesters. In contrast, this is a map of license sales, a human activity, which serves as a surrogate for a FEGS. This metric is a categorical variable mapped by zipcode for a region. Source: (Drewes & Silbernagel, 2004)

3.4 Rivers and Streams

David Peck, U.S. EPA Pacific Ecological Systems Division

Photo: Rivers and streams are important natural capital. The health of the river can impact beneficiary-specific ecosystem services, like recreational anglers or swimmers. Photo credit: EPA Flickr site.

Rivers and streams are vital ecosystems in the United States, which has over 3.5 million miles of rivers and streams with varying uses and conditions (https://www.rivers.gov/waterfacts.php). These ecosystems provide a habitat for fish and other aquatic life. Associated habitats provide necessary food and shelter for many non-aquatic species. Rivers and streams connect major water resources from melting snow high in mountains to estuaries meeting the ocean. Rivers and streams are important for human life by providing essential drinking water, while their commercial uses are geared towards hydropower, irrigation, navigation, industry, and waste removal, with upwards of 750,000 miles of rivers are behind dams to produce hydroelectricity and other commercial goods and services (https://www.rivers.gov/waterfacts.php). The economic and cultural benefits from the recreation and enjoyment of flowing water ecosystems further justify the protection of these ecosystems.

Step 1. Ecosystem Delineation

Rivers and streams are bodies of water which flow from higher to lower elevations. Some rivers and streams flow partially or entirely below the ground. Some are a tiny trickle, and others are more than a mile wide. Rivers and streams can be classified by their size based on the upstream drainage area (i.e., the area where precipitation runs off into streams, rivers, or lakes). For example a stream with a drainage area between 10 and 100 km^2 (39 and 390 mi^2) is classified as a small river (Wang et al., 2011). Alternatively, size and accessibility can be categorized based on "stream order," which is based on how smaller streams join to create larger streams and eventually rivers. Headwater streams (i.e., with no upstream tributaries) are categorized as first order streams; when two first-order streams come together, they create a second-order stream, and so on. Wadable streams are typically first through third order (but in more arid regions, higher order streams may also be wadeable). Rivers are typically sixth-order or greater. Due to the changes in stream order from streams to rivers, there are often clear differences between the biological communities that inhabit each.

Throughout history, many of the rivers and streams in the United States have been channelized or impounded behind dams. These modifications are done to facilitate navigation, reduce flood risk, create power, or allow development of the adjacent land. Rivers are also subject to seasonal changes based on climate and weather. Natural events and cycles of erosion take their toll on rivers, changing the landscapes of many of the rivers we see today. Some of the largest rivers in the United States are critical to the economy, transportation of goods, natural beauty, and energy production from hydroelectric dams. The Mississippi River is the largest river in the United States based on discharge, with a drainage area of almost 1.2 million square miles. Other notable rivers such as the Missouri, Delaware, Columbia, and Colorado Rivers stretch thousands of miles throughout the United States. Their cultural contributions are not to be underestimated, as many of the rivers were once extensively used as transportation corridors for moving goods and connecting civilizations.

Streams are typically wadable but not navigable. Most streams are tributaries to rivers. Many small streams are also seasonal, flowing only during wet periods or following storms. About 90% of the perennial (constant flowing) streams and rivers in the United States are non-navigable. Urban streams receive much of their flow from runoff from impervious surfaces (e.g., pavement).

Step 2. Beneficiary Specification

The rivers and streams team selected five beneficiaries from the NESCS Plus classes that directly benefit or profit from rivers and streams (**Table 9**). These beneficiaries were selected based on their relevance and the availability of data.

Table 9. Available FEGS Metrics for Beneficiaries of Rivers and Streams

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Private energy generators	Thermoelectric cooling	Water	Water quality	Temperature (Long-term measurements of water temperature; Predicted annual and seasonal water temperatures)	NARS; StreamCat	No	No
				pH; Calcium hardness; Alkalinity; Water temperature; Total dissolved solids; Chloride; Sulfate; Alkalinity; Water temperature	NARS	No	No
			Water quantity	Mean Annual Flow	NARS; StreamCat	No	No
		Fauna	Fauna community	Density/abundance of fouling/nuisance/invasive organisms (e.g., Asian clam, zebra mussels)	NARS	No	No
Residential Property Owners	Riverfront property owner	Water	Water quality	Contaminant concentrations (mg/L)	NARS	No	No
				Concentrations of harmful bacteria (e.g., enterococci, E. coli); Presence and/or concentration of cyanobacteria in water (cells/mL)	NARS	No	No
		Composite	Extreme events	Annual risk of flooding GIS layer with elevations and floodplain delineations; FEMA maps, risks of flooding	NARS; EnviroAtlas	No	Yes
			Site Appeal	Observations of presence or extent of surface films or odors in water	NARS	No	No
People Who Care	Existence values	Fauna	Fauna community	Taxonomic count data with autecological and tolerance assignments / O/E scores / species richness of macroinvertebrate community	NARS	No	Yes
Waders, Swimmers, and Divers	Swimmers	Water	Water quality	Chemical contaminant concentrations in water (mg/L)	NARS	No	No
				Biological contaminant Cyanobacteria concentrations in water (cells/mL)	NARS	No	No
				Water clarity (Turbidity (NTU); color (PCU)	NARS	No	No
				Water temperature (F/C)	NARS	No	No
			Water quantity	Water depth measurements (m or cm); either cross-sectional or thalweg	NARS	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Anglers (Recreational)	Catch and release	Water	Water quality	Chemicals contaminant concentrations in water	NARS; EMAP	No	No
				Biological contaminant (Enterococci / cyanobacteria / microcystin and/or cylindrospermopsin concentrations in water	NARS	No	No
				Water clarity Turbidity (NTU); color (PCU)	NARS	No	No
		Fauna	Fauna community	Presence, richness, and abundance of desirable fish species/Number of "trophy" game fish or other charismatic species	NARS	No	No
		Composite	Site appeal	Measurement data on overall rating for site appeal	NARS	No	No
	Catch and eat	Water	Water quality	Chemical contaminant concentrations in water	NARS; EMAP	No	No
				Biological contaminants Enterococci / Cyanobacteria / Microcystin and/or cylindrospermopsin concentrations in water	NARS	No	No
		Fauna	Edible fauna	Collection data with edible fish species and relative abundance	NARS	No	No
				Relative abundance (or biomass) of edible fish species	NARS	No	No
				Presence and severity of fish anomalies, contaminate levels in fish tissue (ng/g wet wt), potential risk from consuming	NARS, State/Federal fish consumption advisory databases	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Food Subsisters	Anglers (Subsistence)	Water	Water quality	Chemical contaminant concentrations in water	NARS; EMAP	No	No
				Biological contaminants Enterococci / Cyanobacteria / Microcystin and/or cylindrospermopsin concentrations in water	NARS	No	No
		Fauna	Edible fauna	Collection data with edible fish species and relative abundance	NARS	No	No
				Relative abundance (or biomass) of edible fish species	NARS	No	No
				Presence and severity of fish anomalies, contaminate levels in fish tissue (ng/g wet wt), potential risk from consuming	NARS, State/Federal fish consumption advisory databases	No	No

Step 3. Attribute Specification

For rivers and streams, we selected thermoelectric cooling energy plants as the beneficiary example. These power producers draw water from rivers and streams to cool equipment. Consequently, for this beneficiary, the water itself is the primary attribute of interest. Specifically, two subattributes are important to a cooling plant operator: the amount of water available (water quantity subattribute) and water temperature (water quality subattribute). For example, colder water temperature has higher capacity to cool equipment. A second attribute valued by the cooling plant beneficiary is water free of fouling invasive species. This attribute is represented by the fauna attribute category and specified as the fauna community subcategory. Together, these attributes influence plant operations, including profitability and performance.

Step 4. Metric Specification

The candidate metrics were chosen to represent biophysical metrics that are amenable to regional and national-scale assessments, although many of these could be adapted for use at more local scales. The ideal metric for thermoelectric power generators would be an index of the risk of ambient river water damage to piping because of poor water quality and/or from biofouling organisms. This index would be a specified composite of water chemistry metrics that would indicate if a power generator would be able to use the water from the specific river or stream. Available data to understand the water chemistry from state and regional sources includes water pH, hardness, alkalinity, water temperature, total dissolved solids, chloride, and sulfate; relevant biological data would focus on presence/density of biofouling organisms. The data that can be used as metrics to make a power generator water quality index are available and would need topic experts to create the ideal index to provide an indication of risk.

There are some barriers to the creation of such an index for regional and national metrics. The first would be the inherent differences between the water qualities around the United States and the needs of thermoelectric power generators. The different pH, salinity, dissolved oxygen, and other water chemistry measurements in combination could give a large matrix of complicated issues when trying to identify non-corrosive waters. It may be more feasible to try to get a regional index to similar waterbodies, as expert evaluation is needed to move forward in understanding the potential need and flexibility of an index.

Step 5. Data Sources and Availability

The water chemistry data are available to create a spatially explicit representation of a water quality index used for corrosivity of water in thermoelectric power generator decision making. However, expert and local advice on this measure is needed to create a robust and useful index. The idea behind making a spatially explicit representation would allow for a visualization of the areas of lowest risk to power generation facilities. The survey design for the NARS assessments allows one to estimate the length of streams and rivers in a defined state based on the particular indicator (e.g., the length of rivers that pose low risk of corrosion or scaling), and these estimates can be produced at various scales or for specific components of the river and stream length (e.g., for rivers larger than 5th order, or for a geographic region).

A general constraint of using the NARS data for metrics associated with rivers and streams is the synoptic component of the survey design and the density of sampling sites. Data are collected once from each site during a defined index period (generally the period where flow is stable). Temporally, there could be issues with understanding the entirety of a season in an area from the few NARS data point collections. Metrics or indicators that rely on more intensive sampling at a site are not amenable to assessment (e.g., increased sediment and fertilizer load in the rivers by snow melt and runoff during rainy/wet seasons). While the density of the NARS sampling sites is low, there are approaches that can be used to develop spatial models to predict condition for a specific metric or indicator for river and stream length that is not sampled (e.g., Thornbrugh et al., 2018).

Example Visualizations for FEGS Metrics in Rivers and Streams

The survey design for the National Rivers and Streams Assessment component of NARS allows for inferences to be made from the set of sampled sites to a much larger population (in the same manner as public opinion polls). The population in this case is defined as the total length of all streams and rivers that had flowing water in them when they were sampled. Assessment questions that are appropriate for the National Rivers and Streams Assessment are of the general form: “What is the total length of stream that is in acceptable (or unacceptable) condition to a specific beneficiary based on a given FEGS metric?”

For a benficiary interested in river and stream water an an acceptable source of cooling water, the metric might represent a combination of water quantity, water quality (in terms of temperature and corrosion or scaling potential), and the potential for biofouling, and the assessment question could be phrased as: “What is the length of the river and stream network that has sufficient water quantity, acceptable temperature to provide adequate cooling, and a low risk of scaling, corrosion, or biofouling?” As this metric has not been developed yet, we provide a visualization example for another potential beneficiary, but the general presentation would be similar for a metric associated with the availability and quality of cooling water, or any other metric with a categorical representation.

A simpler assessment question is possible for a non-use beneficiary. The example metric is an index of biological condition of the benthic invertebrate community that is found on the bottom of rivers and streams. The structure (in terms of what species of organisms are present) and the composition (how individuals are allocated among the species present) of this community are affected by various types of human disturbance. The assessment question in this example is: "What is the length of the river and stream network that has benthic invertebrate communities that are similar to what is expected in rivers and streams that have the lowest intensity of human disturbance?" This metric is a biophysical quantity that is a reasonable representation of the concept of biotic integrity that matters directly to an existence beneficiary (e.g., Johnston, Segerson, Schultz, Besedin, & Ramachandran, 2011).

Figure 10 is an example graphic that addresses this assessment question, and can be modified to address the general form of the question. The left panel presents stream/river length estimates in terms of the percent of total length, while the right panel presents the actual estimated stream lengths. The bars represent various classes of condition. In this example, "Good" means the index values are similar to values expected in least-disturbed sites. "Poor" means the index values are not similar to the values observed in least-disturbed sites, and "Fair" means values are somewhat similar to values observed in least-disturbed sites. Results are shown for different regions of the country, but one can define other spatial domains, such as river basin, stream size classes, or ownership. If a cooling water metric were available, one could produce a similar-looking graphic where "Good" would represent conditions that are associated with adequate water quantity, quality, and low risk of biofouling, and "Poor" would represent conditions that are not conducive as a source of cooling water.

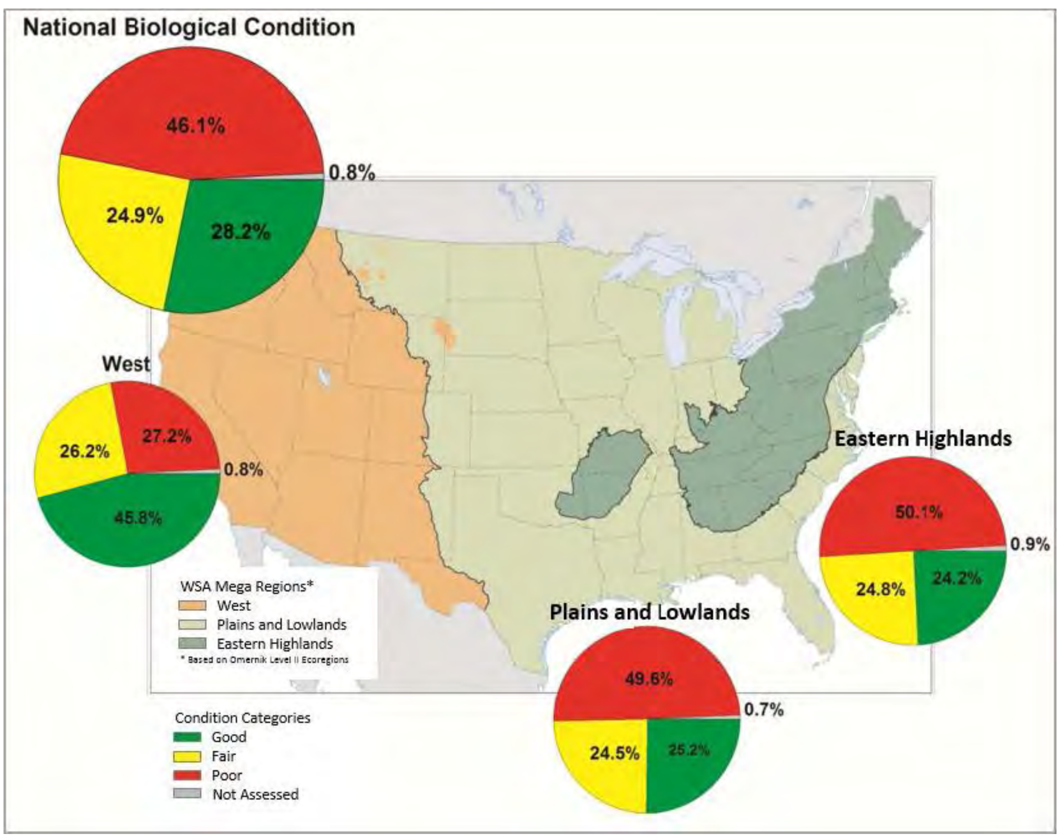


Figure 10. Stream biotic integrity graphed for major regions of the contiguous United States. *Biotic integrity is a measure of a FEGS for nonuse beneficiaries. This is a categorical representation of stream reaches aggregated to major region; this same sort of representation could be applied to the cooling water example with appropriate data. Source: (U.S. EPA, 2016b [National Rivers and Streams Assessment]).*

3.5 Wetlands

Amanda M. Nahlik, U.S. EPA Pacific Ecological Systems Division

Photo: Wetlands are a diverse and everchanging ecosystem that vary across the nation. The cypress swamp pictured above is more typical of the Gulf Coast than where it is actually located – in southern Illinois, the northern most range for this type of wetland ecosystem. Photo credit: (National Wetland Condition Assessment; U.S. EPA, 2016c).

Wetlands are the parts of the landscape that are transition zones from land to water (for at least some of the year). Wetlands can occur along rivers, streams, and lakes or along natural depressions and seeps. Three important features define wetlands: (1) water and wet-adapted plant life; (2) soil conditions that feature evidence of prolonged saturation; and (3) presence of water at or near the soil surface to support the first two features (National Wetland Condition Assessment; U.S. EPA, 2016c). This vitally important ecosystem occupies 5–8% of the Earth's land surface (U.S. EPA, 2016c) and provide important benefits to natural and human communities. These ecosystems provide important intermediate ecosystem services, including flood prevention, water filtration, and wildlife habitat, in addition to the final ecosystem services presented here that are enjoyed by beneficiaries.

Step 1. Ecosystem Delineation

Defining the boundaries of wetlands is an ongoing issue in the aquatic sciences as a whole. One definition of wetlands often used as the standard for setting wetland boundaries is as follows:

> *"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year."* (Cowardin, Carter, Golet, & LaRoe, 1979)

This definition, while specific to wetlands, also innately includes aquatic systems like perennial streams and shallow estuaries. Farmed wetlands may be included in this definition if they were converted to agricultural production prior to 1985 and still meet the specific hydrologic criteria of a jurisdictional wetland; however, prior converted wetlands, which are wetlands converted to agricultural land prior to 1985 but no longer meet the criteria of a jurisdictional wetland, are excluded.

Step 2. Beneficiary Specification

The Wetland team selected five beneficiaries from the NESCS Plus classes (**Table 10**). These beneficiaries were evaluated based on the potential for available data, particularly from the National Wetland Condition Assessment.

Table 10. Available FEGS Metrics for Beneficiaries of Wetlands

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Farmers	Cranberry Farmers	Water	Water quantity	—	—	Yes (ideal metric)	Yes (ideal metric)
		Soil/Substrate	Soil quality	Soil pH, soil type, percent sand	2011 NWCA	No	No
People Who Care	Existence values	Composite	Ecological condition	Vegetation multimetric index or condition class	2011 NWCA	No	Perhaps (using WetCat)

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Boaters	Kayakers, SUPs, and boaters	Water	Water quantity	—	—	Yes (ideal metric)	No
				Surface water depth	2011 NWCA	No	No
			Water quality	Levels of harmful bacteria; levels of chemical contamination	2011 NWCA; EPA sources	No	No
		Composite	Site appeal	—	—	No	No
Hunters	Waterfowl hunters	Fauna	Edible fauna	Waterfowl abundance (State-based catch rates (proxy))	State-based wildlife agency; USFWS	No	No
				Biological and chemical contaminates in meat (Levels of harmful bacteria; levels of chemical contamination)	2011 NWCA; EPA sources	No	No
		Composite	Site appeal	—	—	No	No
Food and Medicine Subsisters	Native American Medicine Subsisters	Flora	Medicinal flora	Plant species composition,plant species richness, plant mean relative cover	2011 NWCA; Native American Ethnobotany Database	No	No
		Water	Water quality	Levels of harmful bacteria; levels of chemical contamination in water and plants	2011 NWCA; EPA sources	No	No

Step 3. Attribute Specification

For wetland systems, we selected cranberry farmers as the beneficiary example to illustrate the FEGS Framework. We selected general attributes from the hierarchical standardized categories listed in Table 4. For this beneficiary, we were parsimonious in selecting main attributes that matter to the farmer. The selected attributes, described in the following paragraphs, influence the geographic location and method by which cranberries may be grown and harvested in addition to the resulting quantity of cranberries that may be grown and harvested.

Flooding is conducted in wetland-soil cranberry bogs for pest management (without the use of chemicals), frost protection, irrigation, and wet harvesting. On the other hand, water is often shunted from cranberry bogs in the late winter to promote plant budding (Sandler & DeMoranville, 2008). Without a proximal water source that the farmer can withdraw water from or deposit water into, cranberries cannot be farmed, and water quantity, measured by the availability of water during the growing and harvest seasons, is important to cranberry farmers because cranberry vines are sensitive to drought. Therefore, a cranberry farmer cares about water first, specifically water quantity, which is listed in the subattribute column.

Soil type, the amount of sand in the soil, and soil pH of a cranberry bog are all critical components for successful cranberry growth. Thus, in addition to water quantity, the cranberry farmer cares about soil quality, which is a subattribute of the soil attribute category.

Step 4. Metric Specification

Metric specification was conducted for five beneficiaries: farmers; people who care (existence values); boaters; hunters; and food and medicine subsisters. A similar approach to developing metrics was conducted for all beneficiaries by (1) developing hypotheses regarding the attributes the beneficiary interacts with, utilizes, or cares about from the environment (based on secondary research, i.e., literature searches) and (2) determining whether data to support the posited attributes exist. In the following examples, we will focus on farmers, hunters, and people who care (existence values) to discuss this process.

Example 1: Famers. For the cranberry farmer, soil metrics can be developed that adequately capture the physical attributes that the beneficiary cares about from the environment; specifcially, soil type, pH, and percent sand. Most of the data needed to represent these metrics exist in either spatial (i.e., geographic information system [GIS]) datasets or from the 2011 NWCA data (U.S. EPA, 2016c). There may even be supplemental data available for soil metrics from the National Resource Conservation Service (SSURGO [Soil Survey Geographic Database]; NRCS, 2020) if the NWCA data does not have sufficient coverage. Conversely, for water quantity, lack of data is a major reason metrics could be developed for this beneficiary; indeed, for most FEGS (or attributes) and most beneficiaries, data do not exist to do anything beyond proposing a hypothetical, ideal metric.

Example 2: Hunters. Waterfowl hunting is a popular activity in wetlands, and entire organizations, such as Ducks Unlimited, exist to protect wetlands and waterfowl populations for hunting. The metrics that were developed adequately capture the attributes that waterfowl hunters care about from the environment. However, unlike the soil metrics developed for the cranberry farmer, which both exist and are ideal, the metrics for populations of animals, like waterfowl, do not exist in ideal form for reporting on a spatial scale that would benefit hunters. Migratory waterfowl population surveys are conducted for some species and in some states by the U.S. Fish and Wildlife Service (e.g., U.S. Fish and Wildlife Service, 2016) and provide status reports on waterfowl populations. However, this information does not provide hunters with information of where to go to hunt specific types of waterfowl. National-scale wetland surveys, such as the NWCA, could provide the spatial information that beneficiaries need, but are limited to a one-day field visit. Furthermore, adding data collection that requires extensive surveying time, such as wildlife surveys, cannot be supported by the NWCA survey.

Example 3: People Who Care (Existence Values). While there may be many different metrics for existence values (e.g., number of threatened, rare, and endangered species; number of charismatic species; percent area of rare or critical habitat type), we hypothesized that ecological condition broadly captures the attribute of wetlands that people care about. In the NWCA, a vegetation multimetric index (VMMI) was used to indicate ecological condition (Magee, Blocksom, & Fennessy, 2019; U.S. EPA, 2016d). The metrics used in the VMMI describe characteristics of the collective vegetation community – not individual taxa.

Step 5. Data Sources and Availability

Wetlands tend to be studied at local and watershed scales, with only a few states having conducted state-wide wetland surveys (e.g., Ohio, Minnesota). Until 2011, national-scale wetland datasets were limited to mapping efforts to report on extent of wetland area; thus there are limited options for publicly available wetland datasets. However, in 2011, the first National Wetland Condition Assessment (NWCA) was conducted, one of the aquatic resources assessed as part of the NARS. One of the challenges of using the NARS data is that the surveys (and data) are designed for national or regional reporting. As such, NARS data are not as helpful for place-specific metric development. So, for example, NARS data does not help determine *where* on the wetland landscape cranberry farmers may best utilize FEGS. The NARS data can only tell how much area across regions or the nation have particular characteristics. Furthermore, combining the coarse NARS data with finer resolution spatial data will be challenging when it comes to indicator development.

Mapping wetlands is challenging, given their spatial and temporal variability and the fact that some wetland types, such as forested wetlands, are nearly impossible to capture without ground-truthing. Maps of high-resolution, consistently delineated wetland boundaries on a national spatial scale do not exist. Wetlands have been identified as a land cover class using satellite data at a 30m-pixel resolution for the National Land Cover Database (NLCD), although when it comes to distinguishing wetland boundaries from other ecosystems, the algorithms used to do so from this satellite imagery provide very different results than other sources, such as the National Wetland Inventory. In contrast, the U.S. Fish and Wildlife Service's (FWS) Status and Trends project has established approximately 5,000 permanent, 4-square-mile plots to identify wetlands using aerial imagery so that changes in wetland area may be monitored over time. While the aerial imagery for these plots is ground-truthed, these plots do not provide coast-to-coast coverage of the United States and are nonexistent in some areas because plots are allocated in proportion to the amount of wetland acreage expected to occur in each state (U.S. FWS, 2017). Wetlands sites surveyed as part of the 2011 NWCA, from which data were used for this exercise, were selected based on a design frame that used the FWS Status and Trends plots (U.S. EPA, 2016c [National Wetland Condition Assessment]).

Example Visualizations for FEGS Metrics in Wetlands

The example metric shown is for the non-use beneficiary, and is the VMMI described above. While every sampled wetland site is assigned a VMMI score between 0 and 100, that continuous information is not easily interpreted. Instead, "good", "fair", and "poor" thresholds were applied by region and wetland type to describe ecological condition of wetlands across the United States. These are shown in **Figure 11**.

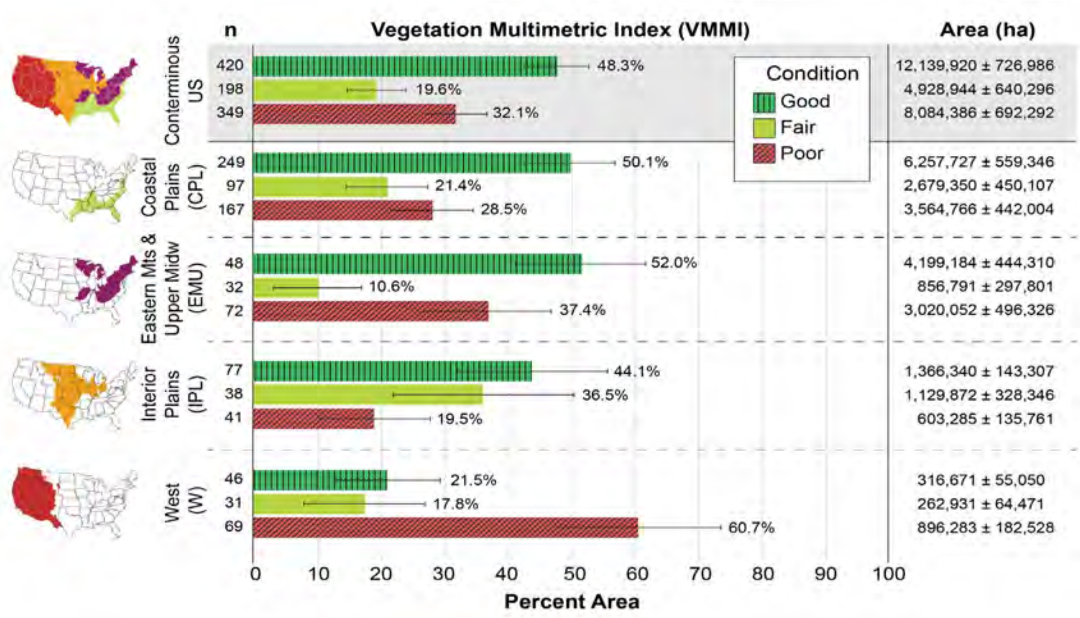


Figure 11. Vegetation condition graphed for major regions of the contiguous United States.
The Vegetation Multimetric index is a measure of a FEGS for a nonuse beneficiary. This is a categorical representation of wetlands aggregated to major regions (U.S. EPA, 2016c [National Wetland Condition Assessment]).

3.6 Agricultural Systems

Timothy Canfield and Kimberly Schuerger
U.S. EPA Groundwater Characterization and Remediation Division

Photo: This picture of an old barn is quintessential Americana and this viewscape is often prized in our culture and arts. Agriculture landscapes like this one combine elements of human capital and labor and contributions from nature, which are challenging to untangle from the FEGS perspective because the line between nature's contribution and human inputs is hard to determine in some cases. Photo credit: EPA Flickr site.

Agriculture makes up one of the largest land-uses in the United States. Grasslands and pasture used for livestock grazing account for 29% of the total U.S. land, and croplands account for 17% (Bigelow, 2017; Bigelow & Borchers, 2017). In total, 1,047 billion acres (46%) of the nation's area is used for agricultural production (Bigelow & Borchers, 2017). Together, agriculture, food, and related industries added more than one trillion dollars to the U.S. Gross Domestic Product in 2017, more than 5% of the nation's total output (USDA, 2020a).

Agriculture systems are an important part of the nation's cultural landscape, cultural history, and remain an important part of the country's cultural heritage. The challenge for this ecosystem within the FEGS framework is that embedded within the agricultural landscape are products of both nature and human labor and capital. Farmland, as depicted in the photo at the beginning of this section, includes natural elements – the soil, climate, wild animals – but also the romanticized old barn, and likely fertilizer on the grasslands. The barn and the whole vista are deeply valued, but the distinction between the natural and built environment is difficult to separate.

Step 1. Ecosystem Delineation

The NESCS Plus defines agroecosystems as those lands that include orchards, vineyards, row crops, tree farms (e.g., Christmas tree farms or short-rotation woody plantations), and pasture/rangelands for livestock (Newcomer-Johnson et al., 2020). Within this framework, we considered many types of farmers and farmlands when we hypothesized the metrics for beneficiaries. There is no single dataset or spatial sampling frame that captures agricultural systems, though USGS Landsat data does classify agriculture as one of its land covers (NLCD; Multi-Resolution Land Characteristics Consortium, 2001).

Step 2. Beneficiary Specification

The Agricultural Systems team selected seven beneficiaries from the NESCS Plus classes (**Table 11**). Farmers were separated into those whose crop is dependent upon pollination (e.g., apples) and those who plant wind-pollinated crops (e.g., row crops, like corn).

Table 11. Available FEGS Metrics for Beneficiaries of Agricultural Systems

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Farmers	Non-pollinator Dependent Crop Farmer	Soil/Substrate	Soil quality	Generic Productivity Index	USDA & MSU	Yes	Yes
	Pollinator-dependent Crop Farmer	Fauna	Pollinating fauna	Population of wild bees	National Websites	Yes	Yes
Residential Property Owners	Farmland property owners	Water	Water quality	Contamination of water	State Websites	No	No
			Water quantity	Groundwater surveys	State Websites	No	No
		Composite	Site appeal	Natural Amenities Index	USDA	Yes	Yes
			Extreme events	Risk of flooding (Flood Maps for 100 year flood risk)	FEMA	Yes	Yes
		Atmosphere	Air quality	Air monitoring data	State Websites	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Hunters (recreational)	Deer Hunters	Fauna	Edible fauna	Deer density status and trends monitoring	State and National Websites	No	No
				Summary of Illinois Deer Seasons	State and National Websites	No	No
				Range-wide status of Mule Deer and Black Tailed Deer.	State and National Websites	No	No
				Deer density United States, 2008	State and National Websites	No	No
				Deer Harvest Reports by Season	State Websites	No	No
				Chronic Wasting Disease Surveillance	State Websites	No	No
				Levels of chemical contaminants in population	National Websites	Yes	Yes
	Waterfowl Hunters	Fauna	Edible fauna	Population reports for abundancy information for hunters.	State Websites	No	No
				Sex ratios of harvested waterfowl to determine if male or female is preferred.	National Websites	No	No
				Migratory bird hunting activity and harvest during the 2014-15 hunting seasons.	National Websites	No	Yes
				Preferred season dates from hunter survey and activity based off of time of year.	Local Websites	No	Yes
				Waterfowl harvest reports by season (surrogate)	National, state Websites	Yes	Yes
				Levels of chemical or biological contaminants in population	National Websites	Yes	Yes
				Reported cases of affected waterfowl	National Websites	Yes	Yes
	Small Game Hunters	Fauna	Edible fauna	Small game population	State and National Websites	No	No
				Harvest Data	State and National Websites	No	No
				Presence/Albescence of Pathogens and Parasites	National Websites	Yes	Yes
				Distribution of Small Game Habitat	State Websites	Yes	Yes

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Agricultural Landscape (Learning)	Educators/ Researchers	Water	Water quality	Nutrient levels in surrounding streams and groundwater	National Websites	Yes	Yes
				Water quality readings in the surrounding area (regional)	National Websites	Yes	Yes
				Water quality current conditions	National Websites	Yes	Yes
		Soil/Substrate	Soil quality	Soil contaminants	National Websites	Yes	Yes
				Soil quality surveys	National Websites	Yes	Yes
		Fauna	Pollinators	Wild bee abundance	(Koh et al., 2016)	Yes	Yes
			Spiritually/culturally important fauna	Monarch butterfly monitoring	National Websites	No	Yes
			Fauna community	Invasive Species Presence	National Websites	No	Yes

Step 3. Attribute Specification

For farmers, soil is the primary attribute that influences all other decisions a farmer may make. Soil quality is a listed subattribute of the soil category. Carbon and nutrient rich soil may provide most, if not all, of the foundational base for farming activities. Farmers that grow pollinator dependent crops (i.e. apples) also care about wild pollinators, which we represent as pollinating fauna sub-attribute of the more general fauna attribute column.

In addition to the soil, water is the life blood of farming. So farmland owners very much care about water attributes of quantity and quality. Water for irrigation, from a well, pond, or river, is essential for many crops and water salinity can impact soils and irrigation equipment, an example of a water quality attribute. Many farmers also enjoy the aesthetics and sense of place of farms, a composite attribute for site appeal sub-attribute. A potential negative composite attribute is extreme weather events, like flooding or droughts, which farmers often contend with from year to year.

Step 4. Metric Specification

Unlike other ecosystems considered in this report, agricultural ecosystems do not have a single, primary data source or nationwide sampling effort that describe ecosystem status, like NARS for aquatic ecosystems or FIA for forests (Gray, Brandeis, Shaw, McWilliams, & Miles, 2012; Oswalt, Smith, Miles, & Pugh, 2014; Oswalt et al., 2019). There are databases such as the Census of Agriculture (USDA, 2020b) but that database "looks at land use and ownership, operator characteristics, production practices, income and expenditures" so it contains a wealth of important data but it mainly describes human activity that depends on ecosystems – thus it contains surrogate data rather than FEGS data or metrics. Agricultural systems are highly local, and most available data are at the state or county level, often lead by a land-grant university or local NRCS office. Consequently, the ability to scale FEGS metrics from local to regional and national scales is limited. The USGS' Landsat land classification system includes agriculture as one its land use and land cover categories (NLCD; Multi-Resolution Land Characteristics Consortium, 2001), though this is coarsely categorized.

Step 5. Data Sources and Availability

The biggest barrier or constraint is that most of the rendered data is not kept in the public domain. While raw data may be collected by state agencies, the use of these data seem to be restricted to those beneficiary group organizations that put time and money into rendering the data, and thus these data are predominantly available through a subscription service where there is an associated access cost. This makes it difficult to develop a publicly accessible FEGS listing at the local to state scale, let alone a national scale. Some organizations, such as the Quality Deer Management Association, put out an annual report that details quite a bit of information. While this report is searchable online, it contains a fee-based subscription component that provides access to additional information.

Since most of these data are collected at the local and state level, there tends to be a lack of standardization on data collection, including how collected, recorded, and reported. This lack of standardization creates a logistical issue when trying to pull these data together from different states, including ensuring data are all measuring and representing the same thing. Ideally, by harmonizing and standardizing the way these data are collected at the local and state scale, these metrics could be easily applied at multiple scales depending on how the data are aggregated to address scale-dependent questions.

Example Visualizations for FEGS Metrics in Agricultural Systems

Much of the data that are gathered is rendered in tabular format that allows full presentation of the numbers but makes analysis of those numbers time consuming, since these data must be transcribed into a spreadsheet before analysis can begin. Having a standard format that the data are collected and recorded into a spreadsheet that could be combined with other data from different states or regions would help facilitate the development of a regional or national comparison. While it is important to have spreadsheet numbers to make quantitative assessments for whatever metric or parameter is being assessed, it is equally important to develop visuals of these data rendered into a readily understandable format for the beneficiary to use with ease. Data visualization is essential to transfer beneficiary useful information quickly and efficiently to the end user. We present two figures as examples of visually translating FEGS metrics into figures to improve social translation: (1) Soil Productivity Index (**Figure 12**); this map is an example of a method to estimate soil quality for farmers; and (2) an example of a regional estimate of deer density (**Figure 13**), the FEGS metric of choice for hunters. The use of GIS capabilities are helping to render this information more readily as graphics, so that data such as soil productivity or deer densities can be produced with relative ease. It will be essential to provide these visual representations to facilitate information transfer to those resource managers acting on behalf of the beneficiaries rapidly and accurately.

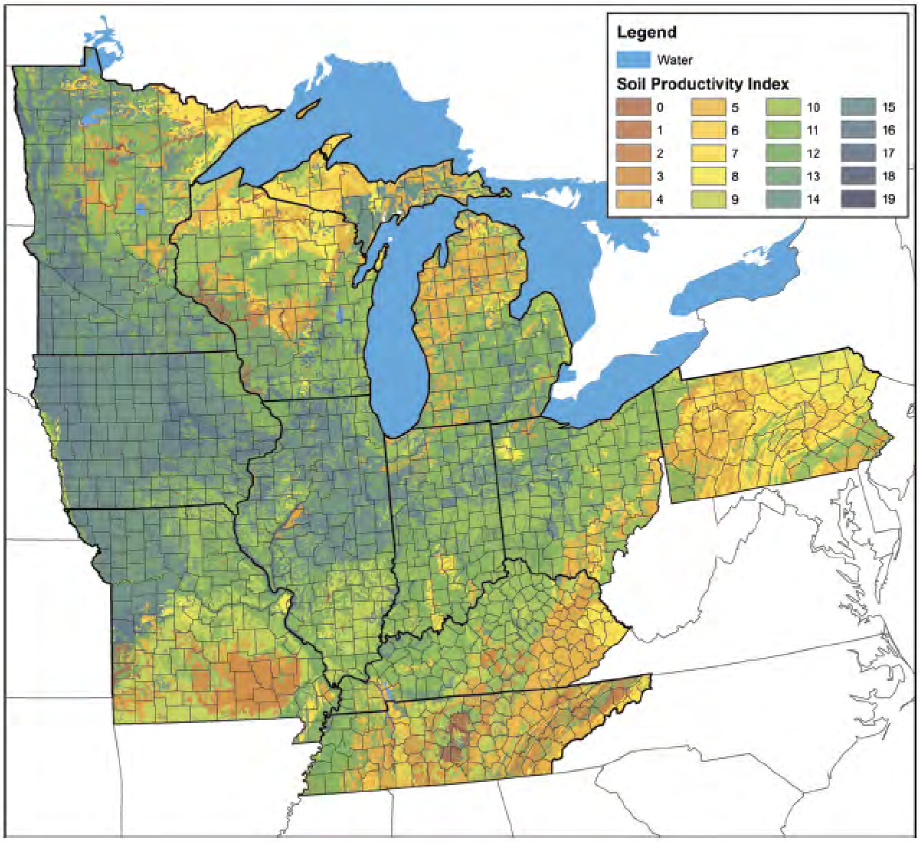


Figure 12. An example of a FEGS metric for soil productivity for farmers (Soil Productivity Index) for Midwestern states.

The higher the soil productivity index, the more likely the soil will support greater crop harvest. This is a representation of a categorical metric mapped at the county level for a major region of the United States. Source: (Schaetzl, Krist Jr, & Miller, 2012)

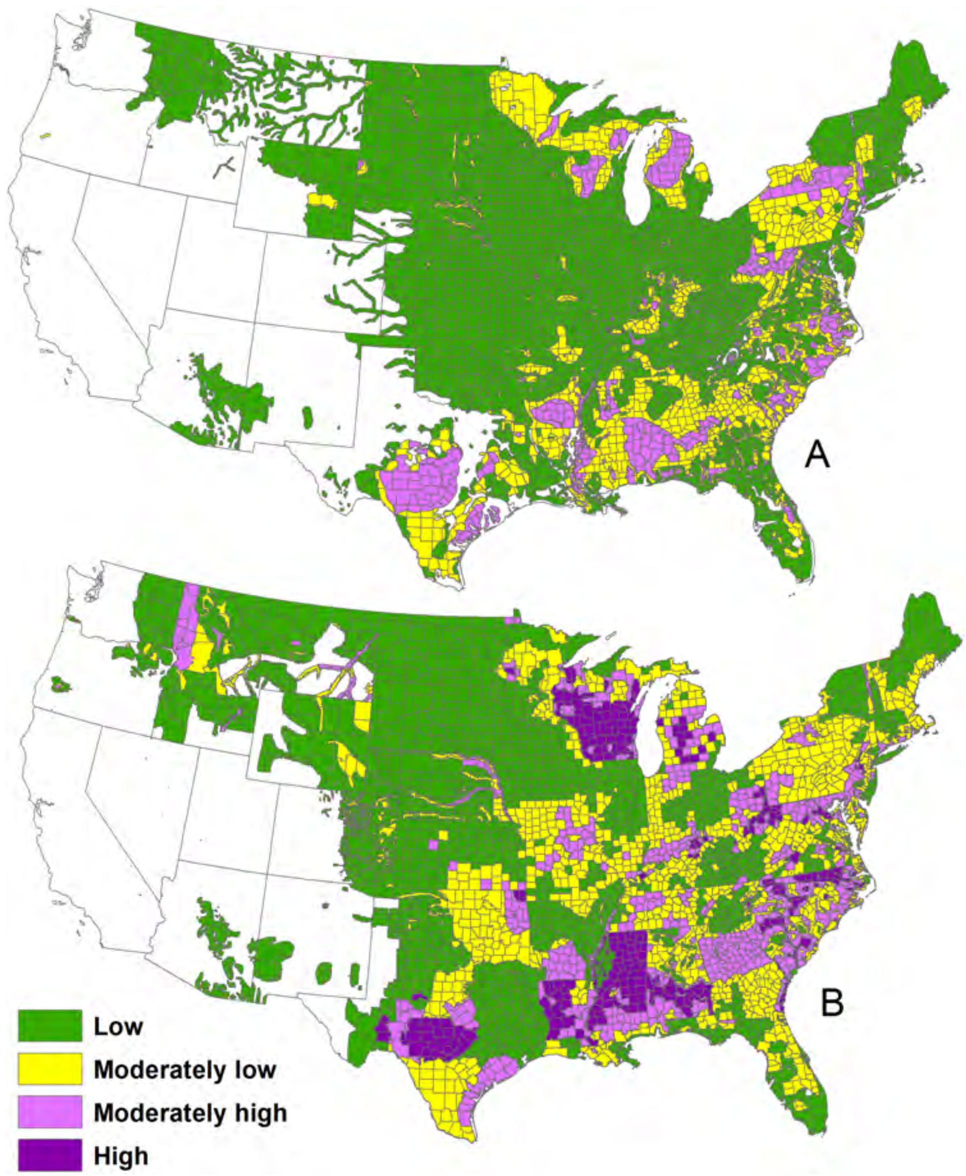


Figure 13. Estimates of deer density across the United States, an example of a spatial visualization of the FEGS metric for deer hunters.

Top: 1982 deer densities; Bottom: 2001-2005 deer densities in the contiguous United States. These are maps of classes of deer density mapped at the county level for the contiguous United States, a categorical metric. Deer density is a measure of a FEGS for Deer Hunters. Source: (Hanberry & Hanberry, 2020)

3.7 Forests

Andrew Gray, USDA Forest Service

Photo: Forests are an important ecosystem in the United States and provide multiple ecosystem services. Standing trees that may be used for building are an example of a FEGS metric for the timber manager beneficiary. Photo credit: USDA Forest Service Flickr site.

For centuries, forests have provided a variety of renewable wood products to the nation, and land that was converted to agriculture. Forests play a key role in providing dependable clean water, which provides drinking water as well as supporting fresh-water aquatic ecosystems and fisheries. Forests also modulate climate and can store (or release) substantial amounts of carbon to or from the atmosphere. Forested lands also provide a range of non-timber products, including edible, medicinal, and decorative plants and fungi; support wildlife populations important to subsistence hunting and recreation; and occupy landscapes valued for their recreational opportunities and aesthetic qualities. Some types of forest conditions, usually those with open canopies and large trees, have been imbued with spiritual value as well. Forests can also threaten human health and well-being by harboring dangerous animals and diseases or by carrying wildfire into populated areas.

Step 1. Ecosystem Delineation

Forest ecosystems are generally described as areas that have some minimum amount of occupancy by trees. Definitions vary in terms of what qualifies as a tree and what should be defined as the minimum area and threshold for tree abundance. The international definition used by most countries reporting to the United Nations’ Global Forest Resource Assessment is land areas of 0.5 ha or more with at least 10% cover of trees taller than 5 m, or where trees are able to reach these thresholds, and primarily under forest land use (Keenan et al., 2015). This includes forested wetlands (e.g., swamps and mangroves), but excludes areas primarily under agricultural or urban land use. This is the definition used by the FIA program, which is mandated to report on the status and trends of forests in the nation (Gray et al., 2012). Forest ecosystems cover 310 million hectares in the United States, or 34% of the land area of the 50 states (Oswalt et al., 2014).

Step 2. Beneficiary Specification

The Forest team selected six beneficiaries from the NESCS Plus classes that reflect a variety of types of FEGS with a range of available data and complexity (**Table 12**).

Table 12. Available FEGS Metrics for Beneficiaries of Forests

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Foresters	Timberland owner/timber grower	Soil/Substrate	Soil Quality	Site class: estimated potential wood production for "normal" stand (m3/ha/yr)	FIA	Yes	Yes
		Flora	Commercially important taxa	Quantity of merchantable volume (m3 or board-ft/ha)	FIA	Yes	Yes
				Quality of merchantable volume	FIA	No	No
Timber, Fiber, and Ornamental Extractors	Timber extractor	Flora	Commercially important taxa	Volume - quantity of merchantable volume (m3 or board-ft/ha)	FIA	Yes	Yes
				Quality of merchantable volume	FIA	No	No
Residential Property Owners	Home owner with some trees living next to forested area	Fauna	Pest fauna	Species lists of regional wildlife	State wildlife agencies	No	No
		Composite	Extreme events	Forest fire - Modeled fire risk given climatic fire regime	LANDFIRE program	Yes	Yes
			Site appeal	—	—	No	No
People Who Care - Existence	Existence values	Composite	Ecological condition	Terrestrial condition assessment scores (1-5)	Cleland et al. (2017)	Yes	Yes
Food Pickers and Gatherers (Recreational)	Recreational huckleberry picker	Flora	Edible flora	Cover of huckleberry species	FIA	No	No
				Cover of huckleberry species in different forest conditions	FIA	No	No
		Composite	Site appeal	—	—	No	No

1	2	3	4	5	6	7	8
Beneficiary Subclass	Specific Beneficiary	Attribute Category	Attribute Subcategory	Available FEGS Metric	Suggested Source	Remotely sensed?	Model available?
Food and Medicinal Subsisters	Elk hunter	Fauna	Edible fauna	Estimates of game populations for selected areas	State game department population estimates	No	No
				Occasional estimates of game populations for selected areas	State game department population estimates	No	No

Step 3. Attribute Specification

Of the six forest beneficiaries, we selected recreational berry pickers to illustrate the FEGS methodology for attribute specification. We used the standardized hierarchical categories in Table 4 to describe the FEGS metrics attributes. For berry pickers, they care about the flora community, specifically the edible or commercially important floral species that are categorized as subattributes of the flora community. Berry pickers also value the whole experience of berry picking, the sights, sounds, smells, and tastes of the forest environment and its flora. This attribute is described as a composite category in Table 4. The overall "gestalt" of the berry picking is categorized as site appeal subattribute.

Step 4. Metric Specification

For the forester and commercial extractor beneficiaries, the FEGS metrics are concrete and there are well-developed national monitoring systems available, primarily through the FIA program (Gillespie, 1999). For the food gatherer and food subsister categories, the FEGS are concrete, but the available information to estimate them is incomplete and fragmentary. For the residential property owner and non-use categories, the FEGS are somewhat nebulous and the type and amount of information available to estimate them is unclear. Some of the categories have several FEGS which cross ecosystem boundaries. For example, fauna used for subsistence, for example deer and elk, often rely on water, forest, and range ecosystems for their survival.

The ideal metric for the FEGS of huckleberries for recreational pickers is the abundance and quality (taste) of huckleberries available in a particular area of interest. The available metric is the cover of each species. This metric could be improved by collecting both FIA protocols (extensive and intensive) on a subset of plots to estimate the amount of cover missed by using the 3% cover minimum threshold on the standard plots. The metric could also be improved for some species by collecting inventory or monitoring data on non-forest alpine or subalpine ecosystems. While it would be impossible to visit every field plot when it is most likely to have fruit, it might be possible to quantify fruit abundance when present in order to build habitat production models to apply to the overall dataset and estimate fruit production (i.e., develop an ecological production function). Quantifying fruit quality might be difficult given variation in beneficiaries' tastes, but simple classifications of fruit might be feasible (e.g., plump, dry, seedy).

The example of huckleberries in forested environments is broadly analogous to a wide range of FEGS related to forest plants. The FIA sampling approach currently can do an adequate job of estimating the cover of species, but this is not usually the attribute of interest. For example, commercial pickers of floral greens focus on plants that are in good condition (e.g, vigorous, fresh, without damage or other blemishes). It is possible that additional measurements or other research can be applied to FIA measures of plant cover and height to provide modeled estimates of FEGS abundance. Similarly, a better understanding of what is missed with the 3% cover minimum would be useful. Species where individual plants tend to have a large growth habit (e.g., many shrubs) are more likely to meet the 3% cover threshold than species with small individuals (e.g., many forbs) or those that tend to be found in a dispersed rather than a clumped pattern. The FIA methodology is unlikely to be modified in the near future, but the program is responsive to user needs and tries to accommodate ancillary studies.

Step 5. Data Sources and Availability

Understory plant species data are currently collected by FIA only in the western states of the United States (including Alaska and Hawaii). Prior to 2000, these data were collected on only particular ownerships and states, and in some cases the quality may have been lower than currently is the case (e.g., species identified only to genus). Since 2000, the data are more consistent and comprehensive, with one tenth of the plots being measured each year in a spatially balanced design with the intention of resampling plots on a 10-year interval. The detailed all-species data were collected on a subset of plots in some years, with the most complete sampling occurring in the north-eastern states of the U.S. from approximately 2001–2009. These data could be useful for estimates at broader spatial domains for the northeast and could inform estimates of the abundance of plants missed by the standard data collection on western plots.

One challenge of the FEGS perspective for forest ecosystems regarding forests is that many of the ecosystem services that forests provide are intermediate services, such as water purification, carbon sequestration, and wildlife habitat. For these intermediate services, it is important to be clear and link them directly to the FEGS biophysical metric—water quality and quantity, standing trees and wildlife populations, to illustrate the services listed above.

Example Visualizations for FEGS Metrics in Forests

Currently, there are no comprehensive data for huckleberry plants in non-forest alpine or tundra, although some National Forests do apply the FIA measurements on non-forest vegetation types. **Figure 14** provides a visualization of such data for a narrower scope, the State of Washington.

For game and recreational species, whether consumptive (white-tail deer hunting) or non-consumptive (bird watchers), the ideal metric would be estimates of the wild population. However, population estimates are usually lacking and estimates for game species are commonly derived from hunter-reported catch rates (**Figures 15** and **16**).

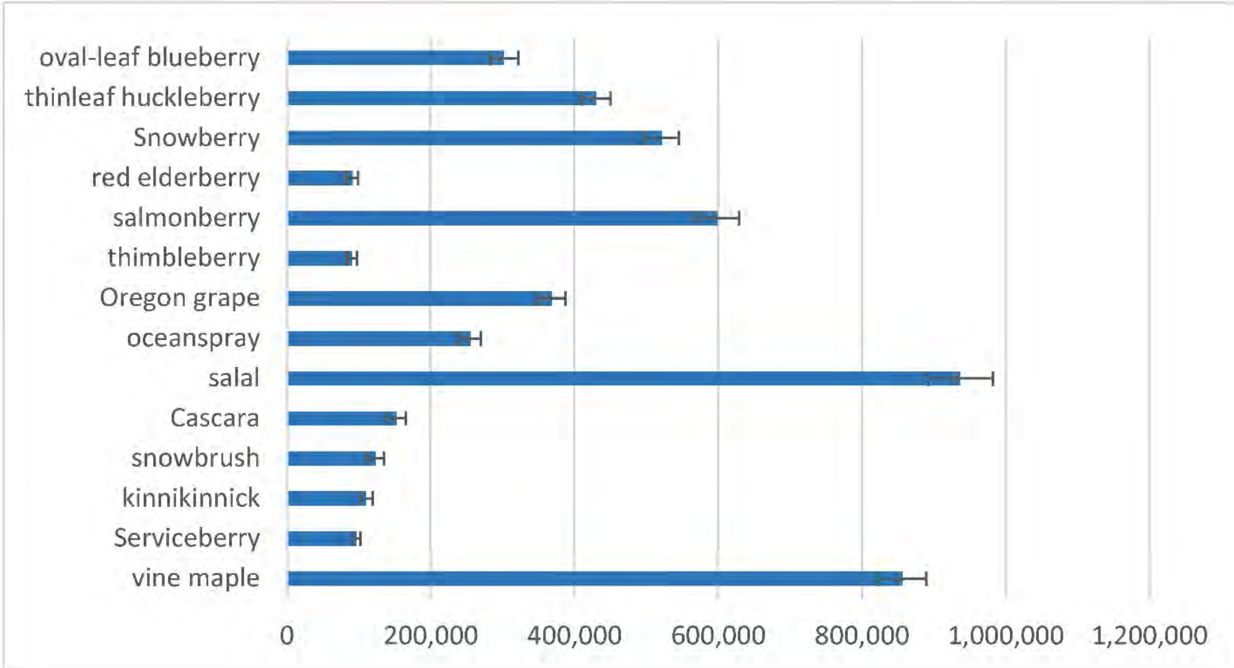


Figure 14. Area of forestland (and standard error) covered by various plant species in Washington state, 2006–2015, based on FIA data.

These species produce FEGS for different non-timber forest-product harvesters, like berry pickers. This is a surrogate for the FEGS metric, cover of huckleberry species, for recreational huckleberry pickers (as well as for other food pickers and gatherers). It is a represented as a continuous variable for a region of the United States.

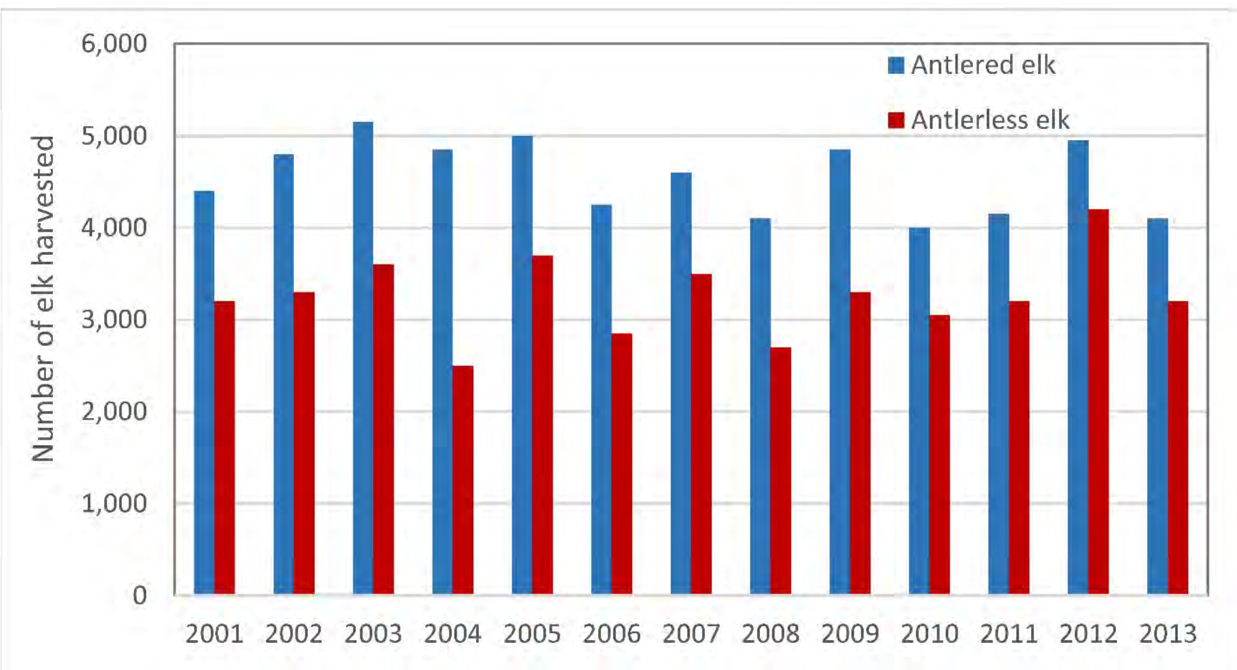


Figure 15. Total antlered and antlerless elk harvested in Washington State (2001-2013).

Source: (WDFW, 2015). This is a surrogate for the FEGS for an elk hunter or for a food subsister. It is a surrogate because a FEGS metric would be the number of elk in the wild, not the number captured. It is a represented as a continuous variable for a region of the United States.

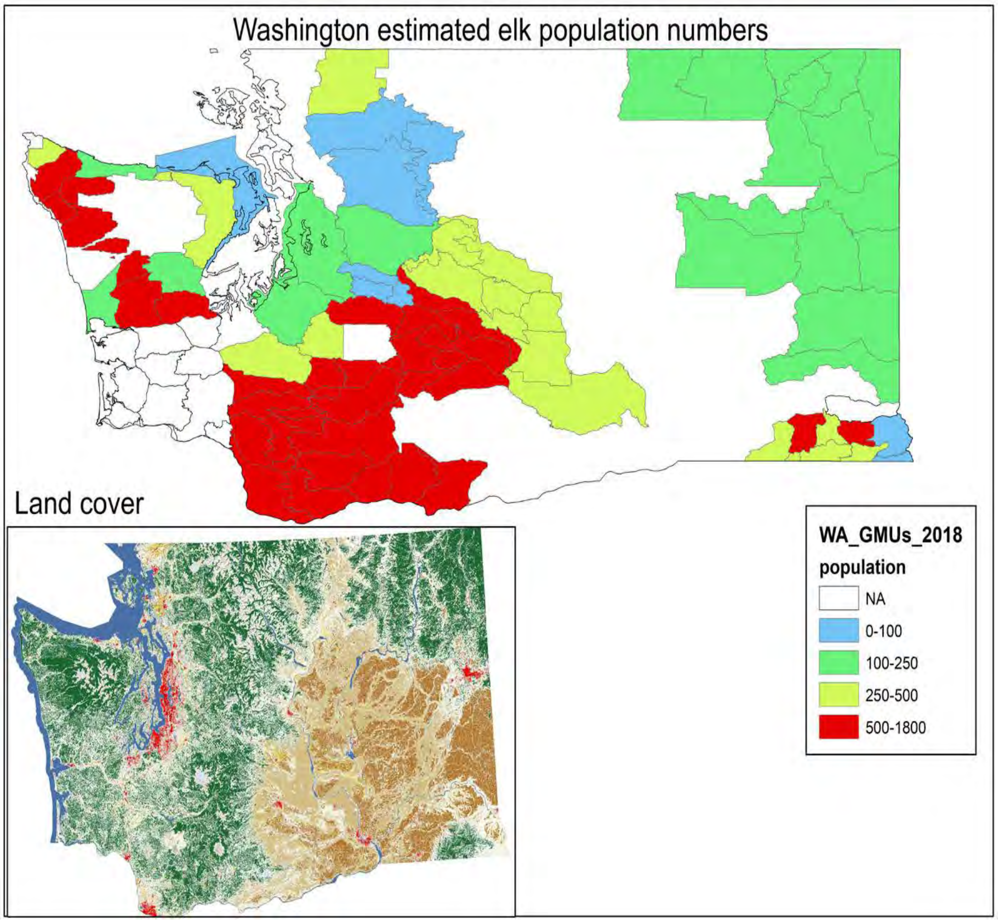


Figure 16. Population estimates for elk in Washington State based on models that relate habitat to categories of elk abundance.

The challenge is these maps do not represent the FEGS metric – the elk – directly, and they demonstrate one of the challenges of mobile organisms that do not obey ecosystem delineation. The representation is of a categorical variable for each of a number of game management units for the state of WA Source: (Multi-Resolution Land Characteristics Consortium, 2001)

3.8 Cross-ecosystem Results Synthesis

We evaluated 45 beneficiaries for seven ecosystems (see Table 3), including both direct consumptive users, non-consumptive direct users, and existence values for non-use beneficiaries. Among the seven General Beneficiary Classes (see Table 3), ecosystem teams selected recreational beneficiaries the most frequently (14 beneficiaries) and Learning beneficiaries the least (1 beneficiary). The teams selected beneficiaries from the remaining beneficiary classes (government, municipal, and residential; agricultural; commercial/industrial; non-use; and subsistence) about equally (5–7 beneficiaries for each).

Among the eight General Attributes (see Table 4), the ecosystem teams identified three the most frequently: fauna, water, and composite/extreme events. Within these attributes, the specific attributes most frequently identified were edible fauna, water quality, and site appeal respectively. This is not a list of general importance; for example, although diverse wild fungi are important for subsistence and commercial beneficiaries in regions of the United States and throughout the globe (Boa, 2004), no ecosystem team identified fungi as an attribute. Rather, this is a reflection of the beneficiaries selected by the ecosystem teams and their understanding of beneficiary preferences.

Ecosystem teams identified 200 metrics for these beneficiaries and attributes; typically 4 to 5 metrics per beneficiary. These are not 200 distinct metrics; for example, “Site Appeal” is identified as an ideal metric three times and “Water Clarity” is identified as an ideal metric four times.

The remainder of this section focuses on four features of our results: the availability of spatially explicit data; the “appropriate” number of metrics per beneficiary; representation of ecosystems for non-use (existence) beneficiaries; and the form(s) of a FEGS metric.

Availability of Spatially Explicit Data

Figure 17 shows the number of metrics identified for the seven General Attributes selected (fungi are omitted as no teams selected fungi as an attribute) and how often the metrics were available on an extensive and spatially explicit basis. Figure 17 demonstrates that FEGS cannot simply be mapped. Of the 200 metrics identified, we found that many (about two-thirds) could not be represented in a spatially explicit manner (e.g., in maps or used in quantitative spatially explicit analyses such as economic analyses where the specification of local scarcity and abundance is important). This finding is reinforced by Tashie and Ringold (2019), who found that there is a paucity of spatially explicit data on FEGS that could be used to map FEGS overall.

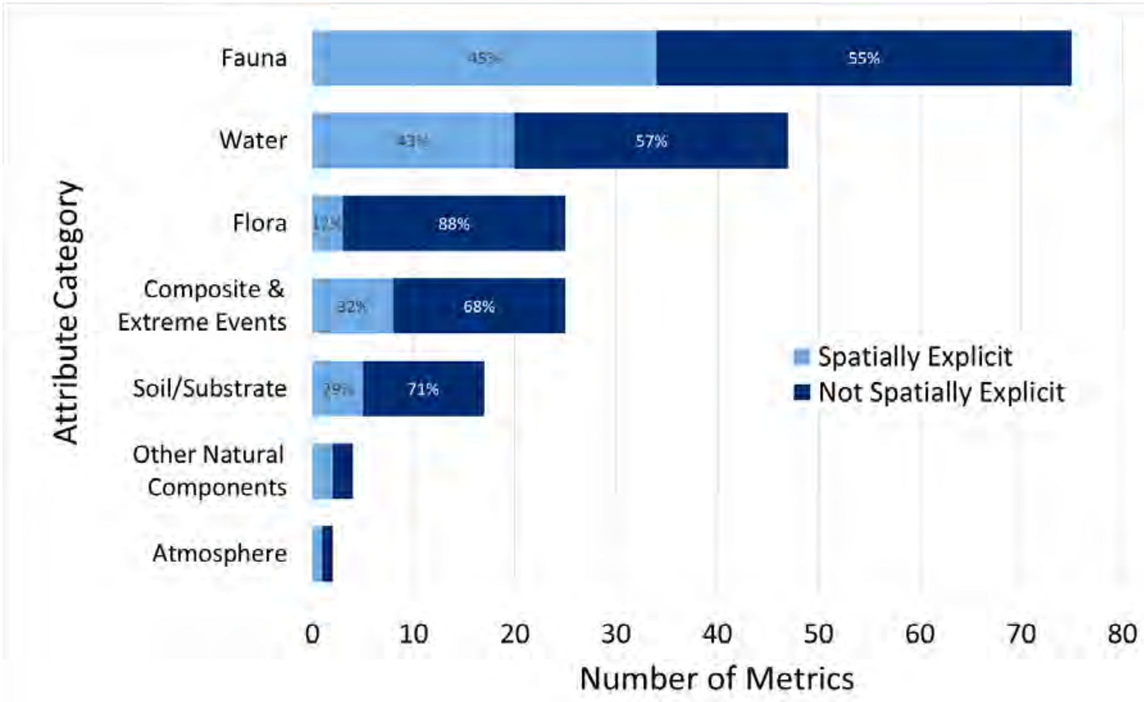


Figure 17. Number of metrics listed for each General Attribute for the 45 beneficiaries analyzed.
Note that some metrics were identified more than once.

Number of Metrics per Beneficiary

The ecosystem experts we convened at our workshops had a range of perspectives on how many metrics are necessary or appropriate for each beneficiary, and we discussed this question at length. Some felt that a beneficiary could only directly experience a single attribute or quality represented by a single metric, and that additional metrics would reflect a different way that people benefit from ecosystems. Others argued that multiple attributes and metrics are important in the way people directly experience or perceive ecosystems. An example helps to illuminate the point: consider a recreational angler; do they directly experience only something about the fish? Or do they also benefit from other aspects of the experience? To the ecosystem experts who support the one beneficiary, one metric perspective, the extent to which the angler also directly experiences and makes decisions on fishing location on the basis of the appeal of a location would make the angler function as two beneficiaries: an angler and a viewer. However, most of the ecosystem teams supported the multi-attribute (and multi-metric) view of a beneficiary (i.e., the angler is one beneficiary with two metrics relating to two attributes, the fish and the view). This perspective is consistent with mainstream consumer theory (e.g., Lancaster, 1966) and with literature on beneficiary decision making. For example, Hunt (2005) and Morton et al. (1993) show for recreational fishing and hunting, respectively, that those beneficiaries make decisions on the basis of multiple factors, including the target organism and the appeal of the site. In the end, we took this latter view, selecting 4–5 metrics on average per beneficiary. This result suggests that communication of ecosystem status and benefits analysis should include multiple metrics.

This question of the number of metrics per beneficiary can be one of deep philosophical interest. A meaningful answer to the question is aided by a specific application rather than the general national and regional charge that we have. For example, if you wanted to examine the benefits of a policy that would change landcover or land use, then metrics of site appeal could well be of great importance for many beneficiaries, including recreational anglers and hunters. If you wanted to examine a policy that would affect lake acidity, other metrics would be important, including fish abundance for recreational anglers, and other attributes might be less relevant. Finally, if you wanted to describe a resource that might be enjoyed or appreciated by a recreational angler, you might want to combine metrics of recreational fish abundance and the appeal of fishing sites (Ringold et al., 2013).

Representation of Ecosystems for Non-use Beneficiaries

All ecosystem teams except the one for agricultural systems identified a possible metric for non-use existence value beneficiaries. In contrast to the other ecosystems considered, agricultural systems are human systems embedded in natural systems, making it hard to identify an existence or non-use value that reflects ecosystem (and not human) activity.

Generally, at the suggestion of the Steering Committee, we selected existence metrics that either (1) represented the status of the biota with respect to an undisturbed reference condition, or (2) focused on an assemblage of organisms for which there is minimal use value, to avoid confusion with direct use metrics. For example, in rivers, the ecosystem team selected a multimetric index of biotic integrity for invertebrates in the water, which is a measure of the biota with respect to least disturbed conditions (Stoddard et al., 2006).[2] A similar index could be constructed for fish or even birds (Bryce, 2006), but both assemblages are often associated with direct use and this can confound the specification of a non-use value.

Form of FEGS Metrics

For metrics of non-use value and other metrics, discussions with members of our Steering Committee also identified issues with respect to the form of the FEGS metric. They suggested that for economic analysis, it is better for biophysical scientists to provide continuous data not paired with a social translation (e.g., specification of good, fair, poor categories). In contrast, many reports that focus on communicating the results of assessments of ecosystems using indices of biotic integrity report the index in a classified form (e.g., good, fair, poor; most disturbed, moderately disturbed, least disturbed). These include all NARS reports and many others (e.g., Jiménez-Valencia, Kaufmann, Sattamini, Mugnai, & Baptista, 2014; Karr, 1991; Llansó, Vølstad, Dauer, & Dew, 2009; Noble, Cowx, Goffaux, & Kestemont, 2007). This suggests that the form of the index for communication may be different than for economic analysis.

We conclude that the appropriate form depends on the specific application and user. Evidence of these multiple forms is apparent in the ecosystem teams' metrics tables. Most of the entries listed as ideal metrics are traditional biophysical measures (e.g., temperature, turbidity, contaminant concentration), but a few, especially associated with site appeal or risk of disease or extreme events, embody a greater level of social translation and suggest a metric in a classified form.

[2] After our work had been completed, a series of focus groups compared ratios of observed taxa to expected taxa (O/E indices) with multimetric indices to evaluate how well they resonate with people. The study concluded that the O/E indices performed better than the multimetric ones (Hill et al., 2020). Had we known of this finding as we developed this report, we would have used O/E indices instead.

3.9 Challenges to Providing Data on FEGS

In this section, we present a synthetic discussion of the challenges in specifying FEGS and providing FEGS data. We identified five core challenges.

1. **We often do not collect attribute data that matters directly for FEGS beneficiaries.** For example, one key attribute not included in the wetlands survey is any measure of site appeal, an attribute listed as being important to two recreational beneficiaries. Comparable NARS surveys include a quantification of site appeal based on field crew judgements. It would be a simple step that could be implemented with little additional field crew burden to transfer the site appeal measure to the wetlands survey. However, field crew quantification of site appeal is not a measure that can be easily used in a fully linked set of models, because it has no quantified link to a biophysical feature that would change in response to a change in policy. From this perspective, aesthetic measures constructed from landscape features (Booth et al., 2017; Daniel, 2001; Frank, Fürst, Koschke, Witt, & Makeschin, 2013; Gobster & Westphal, 2004; Gregory & Davis, 1993; Howley, 2011; Ribe, 1989, 2009) are much more desirable.
2. **In cases where data was collected ostensibly relevant to a FEGS metric, attributes are not collected that directly matter to a beneficiary.** Using the NARS as an example, barriers to closing these gaps range from minor (e.g., fish size) to insurmountable (e.g., a full set of contaminants in fish and in the water). In fact, NARS surveys have added additional information on fish size, which was absent in precursors (Stoddard et al., 2005). Data on fish size has supported the development of a fishery index (Hughes et al., 2021). In contrast, with tens of thousands of inorganic and organic contaminants that could pose a risk to beneficiaries either through water contact or fish consumption, priorities must be set (Hughes & Peck, 2008) to provide a reasonable representation. In another example, the U.S. Forest Service collects understory vegetation estimates based on area, including berry-producing plants. But a berry picker is most interested in the quantity of berries that are produced from the forest vegetation, not the area of production, an example of having the right attribute but wrong metric.
3. **Temporal or spatial characteristics of the data do not provide information at the scales a beneficiary or managers acting on behalf of a beneficiary would find useful.** Even when we are able to collect the right attributes in the right form, this barrier or gap reflects three different facets of time and space: (1) the extent; (2) location, density, or frequency of the data; and (3) the size of the unit being observed.

   The first facet, the *extent* of our consideration, is the national and regional scale. The absence of nationally consistent data is frequently evident in our analyses. For example, 41 of the metrics in the Appendix are listed as being of only local extent, another 5 are listed as being only of state extent, and another 38 are listed as local observations that are aggregated to regions, though with variable methodology that may not support consistent national and regional reporting.

   The second facet is the *location* of the data. Metrics of flooding are directly relevant to many beneficiaries. However, until very recently, many riverside locations subject to flooding were not identified. FEMA has produced flood maps for 61% of the contiguous United States, providing coverage for about a third of the stream miles in the United States. Areas not mapped tend to have limited development but include large areas in agricultural production. Reflecting the need for more extensive coverage, a recent modeling effort provided maps of 100 year floods for the contiguous United States (Woznicki, Baynes, Panlasigui, Mehaffey, & Neale, 2019). Similar modeling efforts (e.g., Fox et al., 2016; Hill et al., 2017) are providing information for biological features that are directly used, enjoyed, or appreciated by beneficiaries (e.g., for existence beneficiaries in aquatic lakes and rivers). These spatial interpolation methods may be of use for other metrics observed in probability surveys for which valuation and other studies require data for locations that not sampled. The way flood probabilities are expressed—typically as the probability of flooding over an extended period of time (e.g., 100 years) or as the annual probability of flooding—also illustrates the need to pay attention to the temporal characteristics of the way in which beneficiaries experience ecosystems. For building owners, a flood at any time of the year can be devastating—thus annual probabilities are meaningful. In contrast, for farmers, while floods at some times of the year are devastating, floods at other times of the year may be beneficial (Dahlke, Brown, Orloff, Putnam, & O'Geen, 2018), thus probabilities of flooding for different seasons of the year may be a more meaningful representation.

The third facet is the *unit of observation*. National economic data may describe, for example, the average household income; national public health data might describe the percentage of adults that are obese. Here the household or adult individuals are the units of observation. Biophysical scientists have similar units, acres of forest or wetland or miles of streams. They have well developed methods for determining how to sample these units for specific purposes. The question this leaves is what is the spatial unit that directly matters to a beneficiary? Do beneficiaries directly experience the number, shoreline length, area, or volume of lakes? This is an important issue that affects the way in which a resource is presented and analyzed. To the extent that resources respond to stressors as a function of their size, this can affect the way in which the magnitude of response to a stressor is understood. For example, the percentage of acidic lakes (acid neutralizing capacity <0) in the northeastern United States in 1984 was 2.5 times larger when expressed in terms of the number of lakes than when expressed in terms of the area of lakes (Linthurst et al., 1986). Repeated discussions in our workshops have led us to conclude that the question of the spatial dimensions of ecological resources directly experienced by beneficiaries is a topic that would benefit from more research.

4. **There is a translation gap among scientists and between scientists and decision-makers and the public.** In some ways, this is the most fundamental gap in providing FEGS. The need to translate information is a fundamental one (e.g., Nicholson et al., 2009; Schiller et al., 2001) and is evident and illustrated in all the indicators developed in this report, especially with regard to their form. The level of translation required for a metric to serve best as a FEGS metric is also an issue that needs attention. In some instances, the capacity to provide a translation is well developed. Regulatory analyses can provide translations of biophysical quantities into units that may be more meaningful to people. For example, EPA analyses of ozone translate technical units (e.g., the fourth-highest daily maximum 8-hour concentration averaged across three consecutive years in parts per million) into levels considered to be safe for sensitive individuals with an adequate margin of safety. The 1996 Safe Drinking Water Act Amendments require EPA to review National Primary Drinking Water Standards once every six years and set levels protective of human health in drinking water. Here, agency standards translate technical

units into levels that protect human health and that water systems can achieve using the best available technology (https://www.epa.gov/dwreginfo/drinking-water-regulations). To be clear, it is not that a regulation makes something a FEGS metric, but that a regulatory process may provide the translation from something very technical to something directly understandable. While such translations are important, additional effort needs to be devoted to how best to describe what we presume to be the right technical metric in a form that matters directly to people.

5. **Sometimes we simply are not able to hypothesize the metrics that matter directly to a beneficiary with any real level of comfort.** The most difficult case here is for existence values. We have hypothesized three sets of biophysical measures for existence values (1) the existence of charismatic or iconic species and places; (2) a set of measures of ecological condition, for example, multimetric indices of biotic integrity or Observed/Expected indices often used in aquatic systems (Hawkins et al., 2000; Karr, 1981; Moss et al., 1987; Stoddard et al., 2008), particularly when the assemblage is one that has minimal use value, such as for periphyton or for macroinvertebrates; and (3) all the metrics for use values. This is an area that would benefit from additional research, especially since existence values may be large (Boyd, 2018; Hewitt, 2018; Johnston, 2018). A state of science review is in development that should help to frame this issue (Boyd et al., In prep).

4. Discussion

4.1 Application and Use of FEGS to Decision-makers

FEGS have several uses for Federal and state agencies and for decision-makers in general. First, the focus on starting with beneficiaries and the provision of a full list of beneficiaries (in Table 2 here and in NESCS Plus) should help decision-makers ensure that their analyses consider the full range of benefits at the design and subsequent stages of a project. Second, FEGS metrics should be candidates for inclusion in agency reporting programs to the general public, as well as to groups of specific beneficiaries and to their representatives and those responsible for managing resources. Third, FEGS metrics should be candidates for inclusion in monitoring programs; equally they should be considered to be the features that ecological models seek to predict. As these tools and data become more abundant, the capacity to estimate benefits arising from candidate changes in policy will be improved (Sinha, Ringold, Van Houtven, & Krupnick, 2018). Most importantly, Federal and state agencies should seek to refine our candidate metrics and generate a set that are most directly meaningful to people.

Many of the concepts behind FEGS are prominently in use in decision-making. For example, EPA’s strategy for water quality standards and criteria quite clearly notes the need to manipulate a range of intermediate features (e.g., dissolved oxygen and contaminants) for the sake of specific beneficial uses, such as the abundance of edible fish (U.S. EPA, 2003b [WQS]). Similarly, analyses of the social cost of carbon illustrate one way in which the value of a series of final goods and services (agricultural production, human health, property damages from floods and others) are linked via quantitative models to sequestered carbon (an intermediate good) (Interagency Working Group on Social Cost of Carbon, 2010). That linkage is then used to identify the value of increments of sequestered carbon. Outside the EPA, other government agencies have begun to incorporate ecosystem services into their planning process, most notably the USDA Forest Service (Scarlett & Boyd, 2015). The Forest Service was directed to include ecosystem services into their decision-making and planning (U.S. Forest Service, 2012), although considerable discretion was allowed for the appropriateness and levels of investment. As a result, the Forest Service often reports only provisioning goods and services like timber in its assessment (Ruhl & Salzman, 2020).

However, while there are abundant examples of the use of FEGS in which intermediate features are managed for the sake of a final good, there are also perplexing cases in which the final ecological good or service appears not to be given adequate attention. For example, some analysts suggest that invasive plants, such as the giant reed (*Arundo donax*), with great capacity to disrupt ecosystems, be used to sequester carbon (Dukes & Mooney, 2004; Richards, 2002; Ringold, Magee, & Peck, 2008; U.S. EPA, 2013). This is perplexing because one goal of sequestering carbon is to minimize the disruption of ecosystems, but that could instead be exacerbated by the use of invasive plants.

Another use of FEGS metrics is to help governments estimate stocks of natural capital for natural capital accounting practices, which have piqued the interest of many governments at different levels and across the globe. The United Nations Environmental Program has proposed a natural capital accounting framework, but the United States has not developed its own accounts. In natural capital accounting, a nation's natural resources and the ecosystem services that flow from these, as raw material – assets – are used to support the economy and understand natural resources and ecosystem health over time. The goal is to translate ecosystem metrics into standard units that could be reported and shared broadly much like gross domestic product is calculated (Boyd et al., 2018). FEGS could be useful in this effort by offering clear, concrete metrics from the nation's ecosystems that could be broadly understood. In addition, because FEGS are defined at a consistent point in the series of linked production, they are ideal for accounting as they help to avoid double counting, such as counting the value of crabs in addition to the value of the habitat necessary but not sufficient to produce them (e.g., Hein, van Koppen, de Groot, & van Ierland, 2006; Keeler et al., 2012; Lele, Springate-Baginski, Lakerveld, Deb, & Dash, 2013; Toman, 1998); e.g. This is a frequently stated concern in studies in which the value of an intermediate ecosystem good or service is counted in addition the value of other intermediate or final ecosystem goods and service. Many of the FEGS metrics shared in this report are based on existing nationwide ecological sampling protocols, providing a potential foundation for elements of natural capital accounting.

4.2 Metric Identification Process and the Classification System

In our process of identifying metrics, we identified some issues with the use of the classification system in NESCS Plus and its predecessors). Some of those issues were noted in the Methods section. An examination of our results expands on or illustrates of those challenges. We have noted that beneficiaries typically directly use, appreciate, or enjoy ecosystem features quantified by multiple metrics. In addition, those metrics may be representations of multiple ecosystems (or environmental classes in NESCS Plus terms). The most prominent example of this is site appeal, one of the more frequent attributes identified by the ecosystem experts. This means that there is a one-to-many relationship between beneficiaries and environmental classes, and that will likely need to be addressed in social analysis, mapping of FEGS, and national accounting systems.

Another issue encountered is the level of resolution of the structural elements of the classification system. For example, the NESCS Plus beneficiary "Food and Medical Subsisters" is represented by three different specific beneficiaries in our report: fishers, wild rice harvesters and Native American medicinal plants harvesters. A different set of metrics is directly important to each. Similarly, the classification system does not identify some highly valued ecosystems. For example, the environmental subclass Estuaries and Near Shore Marine includes estuaries such as the Puget Sound, the Chesapeake Bay, or Galveston Bay and their host of benefits and associated metrics. It is also the environmental subclass that includes coral reefs, which even for similar beneficiaries have a very different set of metrics. To be fair, any classification system will have this limitation, but these examples and our experience point out that NESCS Plus is a higher level classification system whose users may want to identify finer levels of resolution depending on their needs.

4.3 Research Needs

Throughout this project, we used the FEGS Framework to delineate and help select metrics for ecosystem services. Additional efforts are needed to continue to expand upon the ideas presented here. From our process, we identified three areas that warrant further research:

Areas where operationalizing the FEGS concept requires some additional analysis. (See **Section 3.9**, Challenges to Providing Data on FEGS). In certain instances, the FEGS Framework, with its shared definitions, would benefit from additional research. Essentially, where does the FEGS definition and its use of ecosystem-specific beneficiaries work and under what circumstances does it become too rigid to be useful in real-world applications? We encountered these limitations when applying the Framework to beneficiaries and soliciting feedback from one another and our Steering Committee experts, and identified four topics needing additional and concentrated attention: (1) human health linkages with FEGS; (2) freshwater visibility and its relationship with property values; (3) hunters or anglers and highly mobile game species (anadromous fish, deer, birds) that cross ecosystem boundaries; and (4) property owners and flooding risks. These four crosscutting ideas are important starting points for further discussion.

1. **The need to expand beyond the seven ecosystem-specific beneficiaries we present here.** One ecosystem type of special interest is urban and suburban systems, which we have not addressed in this report. These areas are densely populated but the challenge is identifying the contribution of nature in heavily modified landscapes. Like agricultural systems, the line between natural and built is nuanced in cities. FEGS in urban areas need to be evaluated to define boundaries between what is provided by nature and what benefits require significant human input and capital. For example, is a tree planted in a sidewalk planter by a city crew providing an appealing site and shade, sustained with trucked-in soil, fertilizer, and drip irrigation, a quantity whose enumeration would reflect a measure of ecosystem activity? Questions such as this are important because on a daily basis, the contact people have with nature is where they live and 84% of the U.S. population lives in urban areas (United Nations, 2019). Bringing the FEGS perspective into cities and urban planning will require consideration of the boundaries between the natural and built environment, and a clear sense of the direct beneficiaries. While it may provoke interesting philosophical discussions, it is likely that the boundaries will be drawn by clearly stated operational decisions and rules.
2. **The need to critically evaluate the proposed metrics in partnership with social scientists.** We consider the metrics detailed in this report to be "first-generation," and they need further testing and evaluation to ensure that they best represent the linkage

between changes in ecosystems and changes in human well-being. There are four general means by which such testing and evaluation can be done: (1) face validity; this was the primary method we used to evaluate our metrics; (2) reference to beneficiary-specific literature, especially reviews such as Hunt (2005) on recreational fishing, or other primary beneficiary-specific literature, such as Phillips et al (1993) on recreational hunting; Shannon and Grieve (1998) on conductivity and irrigation; or Isom (1986) on Asian Clam biofouling and thermoelectric cooling (although some of that literature focuses on single metrics rather than multiple metrics);(3) reliance on expert opinion or best professional judgment; the application of best professional judgement by economists was behind our design and use of our Steering Committee, although the FEGS metrics for some beneficiaries are best designated by disciplines other than economists; and (4) conducting primary research; for some beneficiaries, this would include the application of social survey methods noted in the methods section.

5. Conclusion

The ecosystem service concept is a powerful way to link and integrate social and ecological sciences into a decision-making context. The beneficiary-first perspective distinguishes the FEGS Framework from other ecosystem service frameworks. The FEGS Framework can facilitate and improve outcomes of ecosystem service analysis by focusing on parts of nature most directly used or enjoyed by people, and selecting biophysical metrics that reflect an ecosystem's ability to provide that ecosystem service of interest. The selected FEGS metrics can then improve the hand-offs between ecosystem production and subsequent social analysis, communication with beneficiaries or tradeoff analysis by policy makers (Boyd et al., 2016).

In this report we suggest metrics for 45 beneficiaries and their interactions with seven ecosystems. This is not an exhaustive list but a place to begin this process; others interested in ecosystem service assessments can build upon this work. They can extend this work to more beneficiaries and ecosystems and to refine our methodology and to adapt our recommendations to specific decision- settings rather than to the general ones described in this report. This report and its metrics are from a national and regional; they illustrate how diverse biophysical scientists translate FEGS concepts into metrics. More detailed study is needed not only to evaluate and refine these metrics, but also to delineate metrics for other specific beneficiaries, ecosystems, and crosscutting issues. Rather, one must begin with considering the beneficiary and user of the ecosystem services first and understand that people interact with and depend on nature in a myriad of ways.

This general report is complemented by beneficiary and ecosystem-specific studies led by social and natural scientists who contributed to this project. One example is the importance of water clarity to many beneficiaries. This topic was explored by Angradi et al. (2018) where they examined regional patterns in lake water clarity. Results from this work found considerable variability not only in water clarity, but also in the ways in which different levels of water clarity translated to qualitative descriptions on a regional basis. Additional FEGS research showed the applicability of FEGS concepts to the delineation of cultural descriptions of medical plants in wetland ecosystems (Nahlik et al., In prep). Other researchers also developed a recreational fishing index from existing stream datasets that focus on game fish desired by anglers (Hughes et al., 2021). This work combined fish taxa, abundance and size data with a set of replacement cost weights to create a place-based estimate of the recreational fishing index for rivers and streams across the country (Hughes et al., 2021). The FEGS concept was also applied to coral reefs where they identified the components of reefs that people directly experience or perceive and that provide ecosystem services to different beneficiaries (Santavy, Horstmann, Sharpe, Yee, & Ringold, in press). We also explored the intangible values of existence values and how best to relate these to biophysical metrics that represent ecological integrity (Boyd et al., In prep). The breadth of these publications demonstrates the organizing ideas of the FEGS concept by identifying metrics from ecological datasets and translating them into a social context and perspectives, thus improving social analysis.

This report is the product of a large interdisciplinary team of natural and social scientists. This collaboration, which began as an ad-hoc group, grew into a formal working group within the EPA and then an interagency team. We identified two key recommendations that can accelerate the selection of FEGS metrics. First, form a strong team of interested experts who understand the ecological systems and value interdisciplinary research. Second, specific to the FEGS Framework, we were reminded to begin with the beneficiaries of interest to the ecosystem – engage early, often, and thoughtfully. Understanding what beneficiaries appreciate and use from an ecosystem is the key to then identify what part of the nature can serve as the metric for evaluation. Then select a final ecosystem good that is causally related in the ecosystem production framework that can be 1) regularly sampled (ideally from an existing sampling methodology); and 2) can be easily understood by other experts and non-experts. The best indicators are easy to understand and as close as possible to what is actually directly perceived to be important by the beneficiary.

This project and report demonstrate the promise and potential for employing FEGS in analysis and decision-making with the goal of more closely linking together social and natural sciences. In the beginning of this report, we describe the need to identify causal linkages between human well-being, ecosystem services, and the environment (Figure 1). This report provides the steps necessary to identify or hypothesize metrics that matter to beneficiaries in a standardized fashion that can assist regional and national ecosystem service analysis.

This report is one part of a suite of related tools developed by the EPA that use the same Framework. They are designed to be useful individually, but even more useful when used together. Another tool is a classification system for ecosystem services. The classification system provides a consistent architecture and taxonomy. It also contains the rationale and a consistent delineation of the three dimensions of our shared Framework— beneficiaries, environmental classes and attributes to be used elsewhere including in this report on metrics. It also contains tables of the relationships between dimensions. It is the National Ecosystem Goods and Services Classification System or NESCS Plus (Newcomer-Johnson et al., 2020). The last part of the FEGS Framework, the FEGS Community Scoping Tool identifies the priority stakeholders, beneficiaries, ecosystem attributes and, in some instances suggests FEGS metrics for use by individual communities (Sharpe et al., 2020).

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